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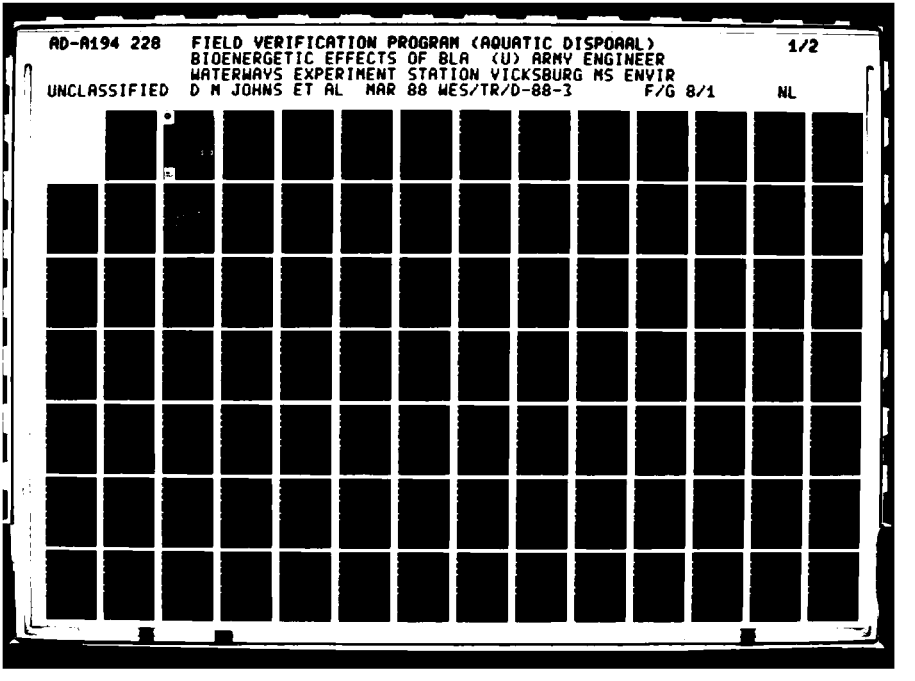

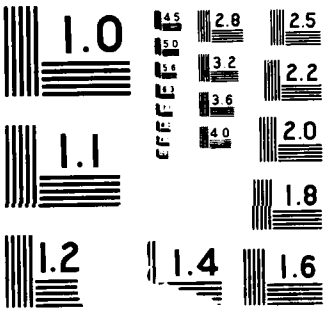
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FIELD VERIFICATION PROGRAM
(AQUATIC DISPOSAL)

TECHNICAL REPORT D-88-3

BIOENERGETIC EFFECTS OF BLACK ROCK HARBOR DREDGED MATERIAL ON THE POLYCHAETE *NEPHTYS INCISA* A FIELD VERIFICATION

by

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March 1988
Final Report

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Environmental Effects of Dredging Programs:

Dredging Operations Technical Support

Long-Term Effects of Dredging Operations

Monitoring and Verification of Methodologies for Evaluation of Environmental Material Disposal Alternatives

Field Verification Program

SUBJECT: Transmittal of Field Verification Program Technical Report Entitled "Bioenergetic Effects of Black Rock Harbor Dredged Material on the Polychaete *Nephtys Incisa*: A Field Verification"

TO: All Report Recipients

1. This is one in a series of scientific reports documenting the findings of studies conducted under the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives (referred to as the Field Verification Program or FVP). This program is a comprehensive evaluation of environmental effects of dredged material disposal under conditions of upland and aquatic disposal and wetland creation.

2. The FVP originated out of the mutual need of both the Corps of Engineers (Corps) and the Environmental Protection Agency (EPA) to continually improve the technical basis for carrying out their shared regulatory missions. The program is an expansion of studies proposed by EPA to the US Army Engineer Division, New England (NED), in support of its regulatory and dredging missions related to dredged material disposal into Long Island Sound. Discussions among the Corps' Waterways Experiment Station (WES), NED, and the EPA Environmental Research Laboratory (ERLN) in Narragansett, RI, made it clear that a dredging project at Black Rock Harbor in Bridgeport, CT, presented a unique opportunity for simultaneous evaluation of aquatic disposal, upland disposal, and wetland creation using the same dredged material. Evaluations were to be based on technology existing within the two agencies or developed during the six-year life of the program.

3. The program is generic in nature and will provide techniques and interpretive approaches applicable to evaluation of many dredging and disposal operations. Consequently, while the studies will provide detailed site-specific information on disposal of material dredged from Black Rock Harbor, they will also have great national significance for the Corps and EPA.

4. The FVP is designed to meet both Agencies' needs to document the effects of disposal under various conditions, provide verification of the predictive accuracy of evaluative techniques now in use, and provide a basis for determining the degree to which biological response is correlated with bioaccumulation of key contaminants in the species under study. The latter is an important aid in interpreting potential biological consequences of bioaccumulation. The program also meets EPA mission needs by providing an opportunity to document the application of the generic predictive hazard-assessment research strategy applicable to all wastes disposed in the aquatic environment. Therefore, the ERLN initiated exposure-assessment studies at the aquatic disposal site. The Corps-sponsored studies on environmental consequences of aquatic disposal will provide the effects assessment necessary to complement the EPA-sponsored exposure assessment, thereby allowing ERLN to develop and apply a hazard-assessment strategy. While not part of the Corps-funded FVP, the EPA exposure-assessment studies will complement the Corps' work, and together the Corps and the EPA studies will satisfy the needs of both agencies.

SUBJECT: Transmittal of Field Verification Program Technical Report entitled "Bioenergetic Effects of Black Rock Harbor Dredged Material on the Polychaete *Nephtys Incisa*: A Field Verification"

5. In recognition of the potential national significance, the Office, Chief of Engineers, approved and funded the studies in January 1982. The work is managed through the Environmental Laboratory's Environmental Effects of Dredging Programs at WES. Studies of the effects of upland disposal and wetland creation were conducted by WES, and studies of aquatic disposal were carried out by the ERLN, applying techniques worked out at the laboratory for evaluating sublethal effects of contaminants on aquatic organisms. These studies were funded by the Corps while salary, support facilities, etc., were provided by EPA. The EPA funding to support the exposure-assessment studies followed in 1983; the exposure-assessment studies are managed and conducted by ERLN.

6. The Corps and EPA are pleased at the opportunity to conduct cooperative research and believe that the value in practical implementation and improvement of environmental regulations of dredged material disposal will be considerable. The studies conducted under this program are scientific in nature and are published in the scientific literature as appropriate and in a series of Corps technical reports. The EPA will publish findings of the exposure-assessment studies in the scientific literature and in EPA report series. The FVP will provide the scientific basis upon which regulatory recommendations will be made and upon which changes in regulatory implementation, and perhaps regulations themselves, will be based. However, the documents produced by the program do not in themselves constitute regulatory guidance from either agency. Regulatory guidance will be provided under separate authority after appropriate technical and administrative assessment of the overall findings of the entire program.

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Agency

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The primary objectives of this study were to test the applicability of biological energy techniques for use with dredged material, to field verify the bioenergetic responses observed in the laboratory, and to determine the degree of correlation between the bioaccumulation of contaminants and bioenergetic responses.

Biological energetics techniques were applied to *Nephtys incisa*, an infaunal polychaete dominant in the benthic community at the Central Long Island Sound disposal site. Comparisons were made between the effects of Black Rock Harbor (BRH) dredged material on the physiology and bioenergetics of juvenile *Nephtys incisa* exposed in the laboratory and the same responses from individuals obtained in the field following the controlled disposal of BRH material. Exposure regimes used in the laboratory studies were similar to the exposure environments that had been predicted around the BRH disposal site.

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19. ABSTRACT (Continued).

The laboratory data indicated that *Nephtys incisa* juveniles living in contaminant-free bedded sediment are physiologically affected when exposed to BRH suspended sediment. Physiological dysfunction observed as a result of laboratory exposure to BRH material included increased maintenance costs, reduced tissue growth, and lowered net growth efficiency.

Physiological changes were also noted in juvenile *Nephtys incisa* collected from the area of the disposal mound. Individual worms collected from stations within the perimeter of the disposal mound (400-m radius) exhibited significant changes in aerobic metabolism and ammonia excretion rates. There was a seasonal pattern in the bioenergetic responses coupled to seawater temperature. The metabolic activity of *N. incisa* was minimal at temperatures below 11° C but increased by factors of 2 to 3 between 11° and 21° C. Within this latter range of temperatures, when metabolic activity was elevated, spatial differences were noted in the bioenergetic responses that parallel exposure to BRH material at the disposal site.

Laboratory derived exposure-response relationships indicated a response threshold of 30 to 50 mg/ℓ suspended BRH sediment. Field exposures were estimated from empirical physical and chemical data and field tissue residue values. These estimates indicate that when significant differences were reported for bioenergetic responses between the reference station and within the perimeter of the disposal mound, the exposures ranged from 51 to 131 mg/ℓ BRH suspended sediment at the sediment/water interface. This range of values is similar to that reported to cause effects under laboratory conditions. There was, however, an important difference between the laboratory and field bioenergetic responses. The field data for stations 200E and 400E indicate significant decreases in respiration rates relative to the REFS station, while the laboratory treatments resulted in significant increases in respiration rates with increasing concentrations of BRH sediment. Multiple routes of exposure are suggested as an explanation for this apparent inconsistency between laboratory and field respiration rates since field *N. incisa* were exposed to both bedded and suspended sediments while the laboratory studies used only suspended sediments. Previous laboratory studies using bedded sediment exposure to *N. incisa* showed comparable patterns of response to the field data.

PREFACE

This report describes work performed by the US Environmental Protection Agency (USEPA), Environmental Research Laboratory (ERLN), Narragansett, R. I., as part of the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program (Field Verification Program (FVP)). The FVP is sponsored by the Office, Chief of Engineers (OCE), and is assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program is to field verify existing techniques for predicting the environmental consequences of dredged material disposal under aquatic, wetland, and upland conditions. The aquatic portion of the FVP was conducted by ERLN, with the wetland and upland portions being conducted by WES.

The principal investigators and the authors of this report were Dr. D. Michael Johns, PTI Environmental Services, and Ms. Ruth Gutjahr-Gobell, Science Applications International Corporation (SAIC).

The laboratory exposure system was designed by Dr. Paul Schauer, University of Phode Island (URI), and Mr. John Sewall, SAIC, provided invaluable assistance with all aspects of the laboratory exposure systems. Mr. Michael Balboni and Dr. Gerald G. Pesch, ERLN, assisted with collecting worms and conducting experiments. Data management was conducted by Mr. Jeffrey Rosen of Computer Sciences Corporation (CSC). The authors wish to thank Dr. John F. Paul, ERLN, for contributions to the field exposure model, and Ms. Joan E. Seites, CSC, for manuscript preparation and word processing support.

Analytical chemistry support was provided by Dr. Gerald Hoffman, Mr. Richard Lapan, Mr. Curtis Norwood, and Mr. Frank Osterman, ERLN; Dr. Richard Pruell, Mr. Richard McKinney, and Ms. Sharon Pavignano, SAIC; and Ms. Kathleen Schweitzer, URI. Dr. James Heltshe, CSC, provided guidance with statistical analysis.

Special thanks are due to Mr. Robert Alix and Dr. Anthony Calabrese of the National Marine Fisheries Service Laboratory, Milford, Conn., for field support and for use of their boat, the *Shang Wheeler*.

The USEPA Technical Director for the FVP was Dr. John H. Gentile, ERLN; the Technical Coordinators were Dr. Gerald Pesch and Mr. Walter B. Galloway, ERLN. Allan D. Beck, ERLN, was Project Manager.

The study was conducted under the direct WES management of Drs. Thomas M. Dillon and Richard K. Peddicord and under the general management of Dr. C. Richard Lee, Chief, Contaminant Mobility and Criteria Group; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, Environmental Laboratory. Manager of the Environmental Effects of Dredging Programs was Dr. Robert M. Engler, with Mr. Robert L. Lazor, FVP Coordinator. This report was edited by Ms. Jessica S. Ruff of the WES Information Products Division.

The OCE Technical Monitors were Drs. John Hall, Robert J. Pierce, and William L. Klesch. The Water Resources Support Center Technical Monitor was Mr. Charles W. Hummer.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

This report should be cited as follows:

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BIOENERGETIC EFFECTS OF BLACK ROCK HARBOR DREDGED MATERIAL ON THE POLYCHAETE *NEPHTYS INCISA*: A FIELD VERIFICATION

PART I: INTRODUCTION

Background

1. The Marine Protection, Research, and Sanctuaries Act (Public Law 92-532) was passed by Congress in 1972. This law states that it is the policy of the United States to regulate disposal of all types of materials into ocean waters and to prevent or strictly limit disposal of any material which would adversely affect human health, welfare, the marine environment, or ecological systems. The implementation of this law, through the issuance of permits as defined in the final regulations and criteria, is shared jointly by the US Environmental Protection Agency (USEPA) and the US Army Corps of Engineers (CE).

2. In 1977, the CE and the USEPA prepared technical guidance for the implementation of the final ocean dumping regulations in the form of a manual entitled "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters" (USEPA/CE 1977). This manual specified which test procedures were to be followed in collection information to be used in making a disposal decision. Among the procedures were those for: (a) chemically characterizing the proposed dredged material; (b) determining the acute toxicity of liquid, suspended particulate, and solid phases; (c) estimating the potential contaminant bioaccumulation; and (d) describing the initial mixing during disposal. These methods have been used for determining the suitability of dredged material for open-water disposal. The procedures in this manual represented the technical state of the art at that time and were never intended to be inflexible methodologies. The recommended test methods were chosen to provide technical information that was consistent with the criteria specified in the regulations. However, use of the manual in the permit process has identified conceptual and technical limitations with the recommended test methods (Gentile and Scott 1986).

3. To meet this critical need, the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal

Alternatives Program or the Field Verification Program (FVP) was authorized in 1982. This 6-year program is sponsored by the Office, Chief of Engineers, and is assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program is to field verify existing test methodologies for predicting the environmental consequences of dredged material disposal under aquatic, wetland, and upland conditions. The aquatic portion of the FVP was conducted by the USEPA Environmental Research Laboratory, Narragansett, R. I. (ERLN). The wetland and upland portions, being conducted by WES, are reported in separate documentation.

4. The USEPA ERLN was responsible for conducting research on the aquatic portion for disposal of dredged material. There were three research objectives for this portion of the program. The first was to demonstrate the applicability of existing test methods to detect and measure effects of dredged material, and to determine the degree of variability and reproducibility inherent in the testing procedure. This phase of the program (Laboratory Documentation) is complete, and the results are published in a series of technical reports. This information provides insight into how the various methods function, their sources of variability, their respective and relative sensitivities to the specific dredged material being tested, and the degree of confidence that can be placed on the data derived from the application of the methods.

5. The second objective was to field verify the laboratory responses by measuring the same response under both laboratory and field exposures. A basic and often implicit assumption is that results derived from laboratory test methods are directly applicable in the field. While this assumption is intuitive, there are no supporting data from studies on complex wastes in the marine environment. The study reported herein offered a unique opportunity to test this basic assumption.

6. The third objective was to determine the degree of correlation of tissue residues resulting from bioaccumulation of dredged material contaminants with biological responses from laboratory and field exposure to dredged material. However, this study was not designed to address cause-effect relationships, and the multicontaminant nature of the dredged material precludes any such assumptions.

Project Description

7. The aquatic disposal portion of the FVP was a site- and waste-specific case study that applied the concepts and principles of risk assessment. The disposal site for the FVP is a historical site known as the Central Long Island Sound (CLIS) disposal site (1.8 by 3.7 km) located approximately 15 km southeast of New Haven, Conn. (Figure 1). The sedimentology at the

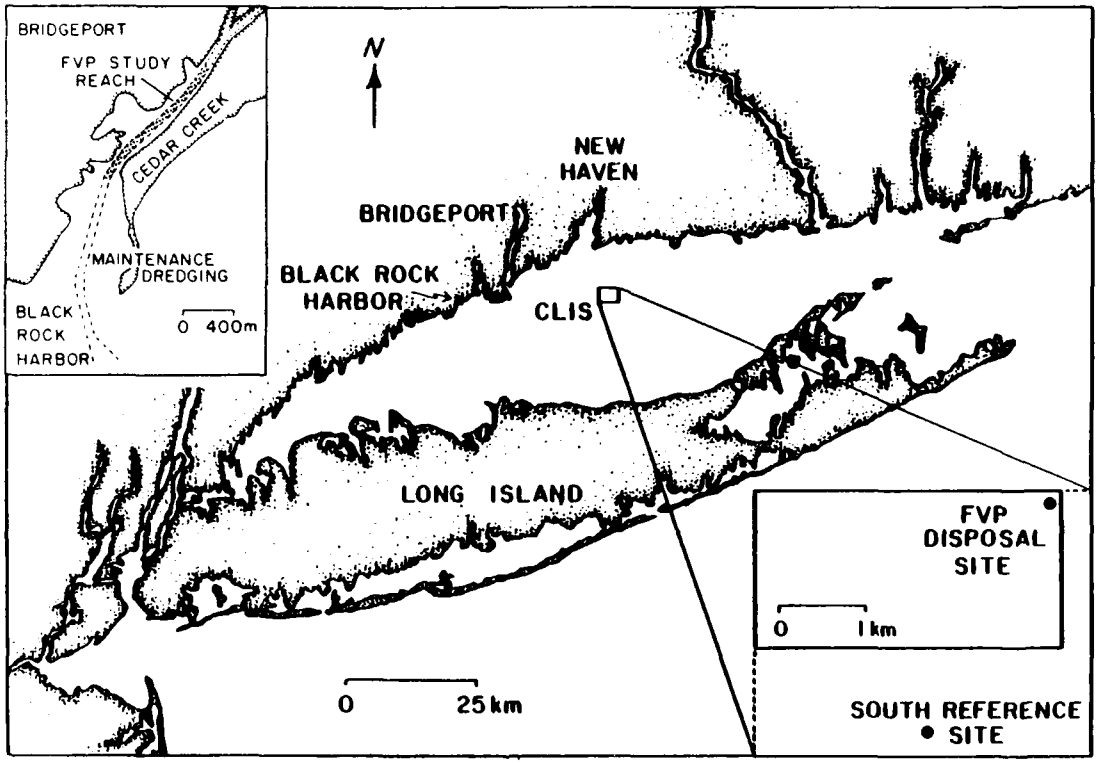

Figure 1. Central Long Island Sound disposal site and Black Rock Harbor dredge site

disposal and reference sites was primarily silt-clay, with a mean grain size of 0.013 mm. Thermal stratification occurs from April to September, and during this period bottom salinity is slightly higher than that of the surface. Tidal currents typically dominate the near-bottom water in an east-west direction. The net bottom drift is to the northwest at 0.5 cm/sec. Suspended sediment concentrations average 10 mg/ℓ, with storm-induced values to 30 mg/ℓ measured 1 m above the bottom. The baseline community data was a homogeneous, mature infaunal community dominated by the polychaete *Nephtys incisa* and the bivalve molluscs *Nucula proxima* and *Yoldia limatula*.

8. The FVP disposal site was selected within the CLIS so as to minimize contamination from other sources, including relic disposal operations or ongoing disposal activities occurring during the study period. This was necessary to ensure a point source of contamination. The uniformity of physical, chemical, and biological properties of the disposal site prior to disposal allowed detection of changes in these properties due to the disposal of the dredged material. Finally, the stations used to study the biological effects in this study were selected along the primary axis of current flow to represent a gradient of potential exposure for the biota (Figure 2).

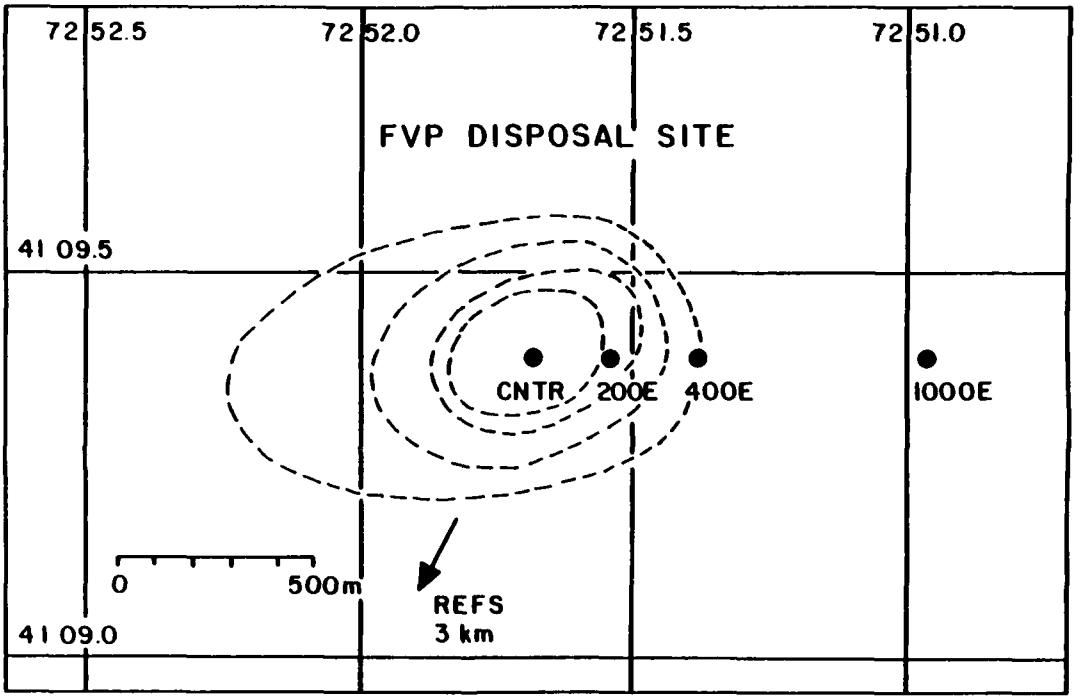

Figure 2. FVP disposal site and station locations

9. The spatial scale of this study was near-field and limited to the immediate vicinity of the disposal site. A primary assumption was that the mound of dredged material constituted a point source of contamination. The temporal scale for the study was 4 years, which included a year of predisposal data collection to define seasonal patterns in the physical, chemical, and biological variables and 3 years of postdisposal data collection to address the objectives of the program and evaluate the long-term impacts of the disposal operation on the surrounding benthic communities.

10. The dredging site was Black Rock Harbor (BRH), located in Bridgeport, Conn., where maintenance dredging provided a channel 46 m wide and

5.2 m deep at mean low water (Figure 1). Approximately 55,000 m^3 of material was dredged during April and May 1983 and disposed in 20 m of water in the northeastern corner of the CLIS disposal site.

11. The dredged material from BRH contained substantial concentrations of both organic and inorganic contaminants (Rogerson, Shimmel, and Hoffman 1985). Polychlorinated biphenyls (PCBs) were present in the dredged material at a concentration of 6,400 ng/g, and polynuclear aromatic hydrocarbons (PAHs) with molecular weights between 166 and 302 were present at concentrations ranging from 1,000 to 12,000 ng/g, respectively. Alkyl homologs of the PAHs were also present in the dredged material at concentrations between 1,000 and 13,000 ng/g. Inorganic contaminants of toxicological importance present in the dredged material include copper (2,900 µg/g), chromium (1,480 µg/g), zinc (1,200 µg/g), lead 380 µg/g), nickel (140 µg/g), cadmium (24 µg/g), and mercury (1.7 µg/g).

Project Scope

12. The FVP is unique among marine research studies for several reasons. The program objectives are directly focused on addressing specific limitations in the methodologies and interpretive framework of the current regulatory process. Among the program strengths were: the development and evaluation of a suite of biological endpoints using the same material; the biological tests represented different levels of biological organization; the tests were conducted under both laboratory and field exposure conditions; tissue residues were examined concurrently with measurements of biological effects; the duration of the study was adequate to evaluate the use of community responses as a benchmark against which other biological responses could be compared; and the project was a site- and waste-specific case study for the application and evaluation of the components of a risk assessment, including the development of methodologies for predicting and measuring field exposures in the water column and benthic compartments. Limitations of this study were: only one dredged material was being evaluated, which constrained certain types of comparisons; the size of the study put limits on the extent to which any given objective was examined; and the resources allocated to determine field exposures were limited. The latter is particularly important because the

laboratory-field comparisons and the risk assessment process both require accurate predictions of environmental exposures.

Laboratory-to-Field Comparisons

13. The field verification of laboratory test methods was designed to compare the exposure-response relationships measured in both the laboratory and the field. Exposure for the purposes of this discussion includes the total dredged material with all of its contaminants. Specific contaminants were used as "tracers" to verify the exposure environment, which is described in terms of BRH dredged material, and to illustrate exposure-response relationships between the laboratory and field. The specific contaminants are a subset of a comprehensive suite of chemicals analyzed in this study and were selected based upon their environmental chemistry and statistical representativeness. The use of specific contaminants in no way implies a cause-and-effect relationship between contaminant and response.

14. Exposure in open marine systems is characterized by highly dynamic temporal and spatial conditions and cannot be completely replicated in laboratory systems. Consequently, the approach chosen for this program was to develop laboratory exposure-response data using only general field exposure information.

Residue-Effects Comparisons

15. Determining the relationship between contaminant tissue residues resulting from bioaccumulation and the biological responses measured is a principal objective of this program. Such relationships do not imply cause and effect; they merely indicate the statistical relationship between an effect and any associated residues. The approach used was to determine specific contaminant residues in the tissues of the organisms as a result of exposure to the whole dredged material in both the laboratory and the field. These residues were determined at the same time that biological responses were being measured. Residue-effect relationships are described and interpreted for both laboratory and field exposures in following sections of this report.

Biological Energetics

16. The regulation of potential pollutants in aquatic environments is generally based upon toxicological information involving the quantification of biological responses with a pollutant concentration for some finite period of exposure. Traditionally, decisions have been made using acute toxicity data where the exposure period was 96 hr and the measured biological response was lethality (Sprague 1976). It is well recognized that this type of information, while useful in some respects, is not adequate to identify acceptable nontoxic levels that are protective of population growth and reproduction (Mount 1968; Sprague 1971, 1976). This limitation has been addressed by the development of a variety of chronic measures to assess pollutant effects on long-term survival, growth, and reproduction (McIntyre and Pearce 1980). In most cases the biological endpoint should provide some measure of an organism's overall health and at least some inference about the organism's ability to carry out normal life processes.

17. An effects measurement technique that may satisfy the preceding criteria is the determination of biological energy balances (Edwards 1978; Johns and Pechenik 1980; Capuzzo and Lancaster 1981; Johns and Miller 1982; McKinney 1982); Johns, Gutjahr-Gobell, and Schauer 1985), along with its corollaries, including scope for growth (Warren and Davis 1967, Bayne 1975). Previous studies using these principles have found a correlation between changes in energy balances or scope for growth and changes in population fitness (Bayne et al. 1979, Gilfillan 1980).

18. In a series of detailed field studies, for example, Gilfillan and his co-workers (Gilfillan and Hanson 1975, Gilfillan et al. 1976) found a reduced scope for growth in the bivalve *Mya arenaria* collected from oil-impacted sites compared to individuals from nearby, relatively clean reference populations. Eventual changes in population structure that Gilfillan could relate to the reduced scope for growth included reductions in yearly growth rate and population density.

PART II: MATERIALS AND METHODS

Laboratory Methods

Sediment collection

19. Two sediment types were used to conduct laboratory tests for the field verification studies. The reference sediment (REF) was collected from the South Reference site in Long Island Sound (40°7.95' N and 72°52.7' W) by Smith-MacIntyre grab (0.1 m^2), press sieved through a 2-mm sieve, and stored at 4° C until used. Prior to dredging, contaminated sediment was collected from Black Rock Harbor (41°9' N and 73°13' W) with a gravity box corer (0.1 m^2) to a depth of 1.2 m, thoroughly mixed, press sieved through a 2-mm sieve, and refrigerated in barrels (4° C) until used. Details of sediment collection and storage procedures may be found in Rogerson, Schimmel, and Hoffman (1985). In all experiments, sediments were allowed to reach test temperature and were mixed prior to use.

Organism collection and holding

20. *Nephtys incisa* for laboratory studies were collected with a Smith-MacIntyre grab sampler (0.1 m^2) at the South Reference site (Figure 1). The sediment containing the *N. incisa* was brought to the laboratory where it was sieved and *N. incisa* juveniles were picked and sorted into relative size classes for experiments. Although somewhat subjective, careful visual separation leads to a coefficient of variation for dry weight of only 24 percent. Other more accurate sizing techniques, such as wet weight determinations, which employ a wet weight to dry weight regression curve, are time consuming and, more importantly, may cause physical damage to the worms because of the handling required.

Suspended sediment dosing system

21. Laboratory studies required the construction of two identical sediment dosing systems to provide either BRH or REF material as suspended sediment simultaneously. Each dosing system (Figure 3) consisted of a conical-shaped slurry reservoir placed in a chilled fiberglass chamber, a diaphragm pump, a 4-ℓ separatory funnel, and several return loops that directed the particulate slurry through dosing valves. The slurry reservoirs (40 cm in diameter by 55 cm high) contained 38 ℓ of slurry comprising 36 ℓ of filtered seawater and 2 ℓ of either BRH or REF sediment. The fiberglass chamber

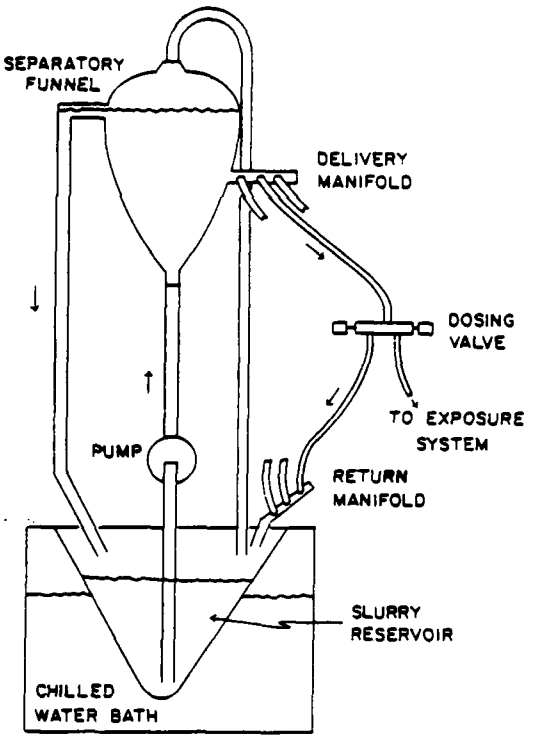

Figure 3. Suspended sediment dosing system

(94 cm long by 61 cm wide by 79 cm high) was maintained between 4° and 10° C using an externally chilled water source to minimize microbial degradation during the test. Polypropylene pipes (3.8-cm-diam) extended to the bottom of the reservoir cones and were connected to pumps (16- to 40-ℓ/min capacity) fitted with Teflon diaphragms. These pumps were used to circulate the slurry while minimizing abrasion that might produce changes in the physical properties (e.g., particle size) of the material. This entire dosing system was maintained under argon gas to minimize oxidation of the sediments.

22. The slurry was pumped up to separatory funnels and returned via an overflow to the reservoir through polypropylene pipes. The separatory funnel provided the constant head pressure needed to circulate the slurry through Teflon tubing to the dosing valves where the slurry was mixed with seawater to provide the desired concentrations for the toxicity tests (Figure 3). Narragansett Bay seawater filtered (to 15 μ) through sand filters was used. Actual concentrations of suspended sediments in the test chamber were determined (by dry weights) periodically (Lake, Hoffman, and Schimmel 1985).

23. The REF and BRH sediments used in this experiment were oxidized before they were placed into the dosing system. In order to obtain consistent

states of oxidation for both REF and BRH sediments, 2 ℓ of sediment were transferred to an inverted polycarbonate carboy and diluted to 19 ℓ with filtered natural seawater at room temperature and aerated for 3 to 4 days. The contents were transferred to the composite dosing system reservoir and diluted to 38 ℓ with natural seawater. Chemical oxygen demand measurements indicated that this time period was sufficient to satisfy the immediate oxygen demand of the sediments.

Exposure chamber for bioenergetics

24. In the laboratory tests with *N. incisa*, the dosing system was set to maintain nominal concentrations of 200 mg/ℓ (dry weight) of suspended sediments with seawater flow rates producing five volume replacements per exposure chamber per day. These flow rates meet the minimum recommended by the American Society for Testing and Materials (ASTM 1980) and were intended to maximize residence time of the suspended sediments in the exposure chambers.

25. A suspended sediment proportional diluter (Figure 4) was used to mix the small quantities of concentrated sediment slurries (10 to 20 g/ℓ) from the sediment dosing system with filtered seawater to produce dilute sediment suspensions in the milligram per litre range. It then combined slurries of different types (e.g., REF and BRH sediment suspensions) proportionally to maintain the same concentration of suspended sediment with different ratios of the two sediments.

26. The exposure chamber for *N. incisa* is illustrated in Figure 5. Polycarbonate bottles (19 ℓ) used commercially for shipping spring water were cut off at the top. Reference sediment (2 ℓ/chamber) was added to a depth of 4 cm and plexiglass strips were inserted into the sediment, dividing it into pie-shaped sections. This permitted subsampling without disturbing the entire chamber. Each chamber was filled with filtered seawater at 20° C. After the sediment in the chambers was permitted to settle and equilibrate for about 4 hr, *N. incisa* were added, and an additional 2 hr was allowed for the worms to burrow into the sediment. The delivery tubes from the proportional diluter were then put in place and a low-pressure airlift turned on to keep the dosed sediments in suspension. This system allowed very little sediment deposition during the course of experiments. Excess seawater was permitted to overflow the brim of each chamber. Earlier experiments indicated that once the worms burrowed into clean reference sediment, they would not attempt to escape. Therefore, the chamber design used here was considered acceptable.

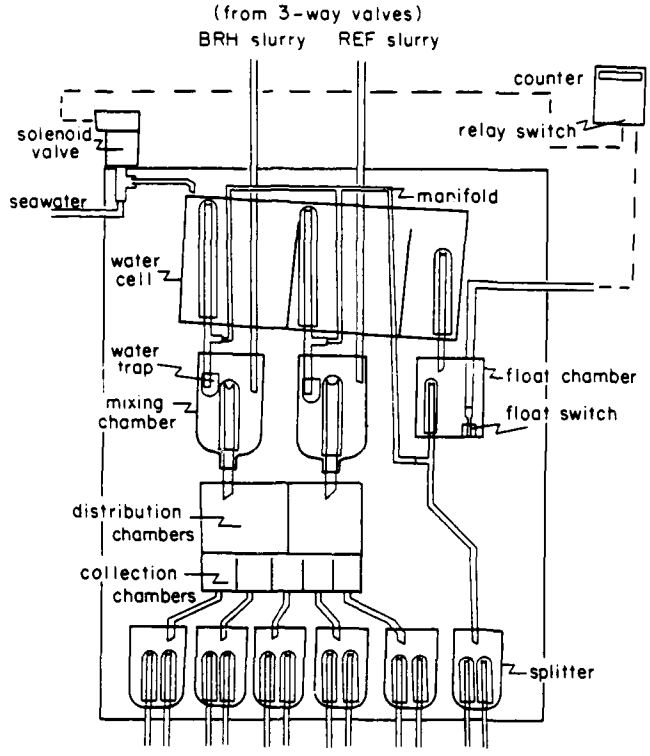

Figure 4. Proportional diluter used to deliver suspended sediment to the *N. incisa* exposure chambers for bioenergetics study

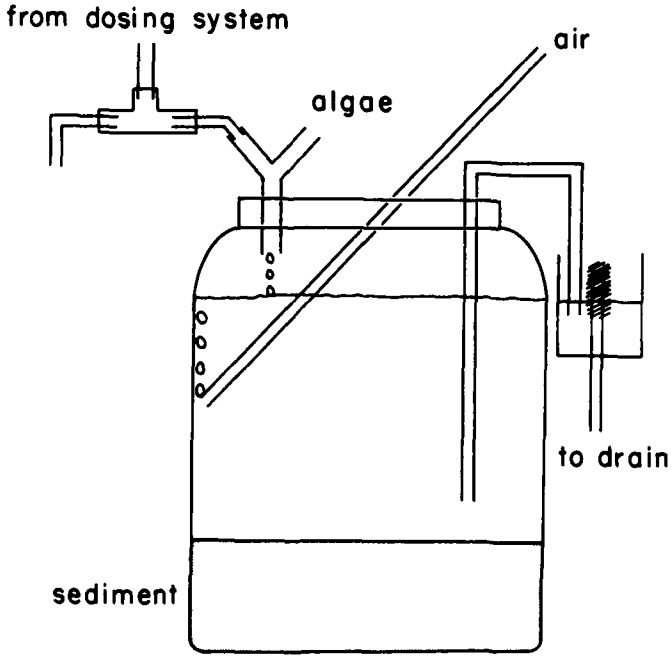

Figure 5. Exposure chamber for bioenergetics study

Experimental design
for bioenergetics study

27. This experiment had exposure conditions of 100-, 50-, and 0-percent BRH suspended sediment. Worms were removed at prescribed times during the experimental period. A total of four laboratory bioenergetic experiments were conducted with *N. incisa* juveniles. In the first two experiments (Experiment 1 and Experiment 2), worms were exposed to oxidized REF and BRH suspended particles in various combinations at a concentration of 200 mg/ℓ for a period of 10 days. In the other two experiments (Experiment 3 and Experiment 4), juvenile worms were exposed to the same concentration of suspended particles, but the length of the experiment was 28 days for Experiment 3 and 42 days for Experiment 4.

28. In Experiments 1 and 2 the only time worms were sampled for physiological measurements was at the end of the 10-day exposure. With Experiment 4, however, an intermediate sample was taken at day 28. The intermediate samples provided comparative data to at least one of the sampling times of Experiment 3. For example, data from the day 28 intermediate sample of Experiment 4 could be compared with the 28-day results of Experiment 3.

29. In Experiment 4, both bioenergetics and tissue residue measurements were conducted on worms removed at time zero, day 28 and day 42. This experiment was supported with chemical analyses of the seawater and *N. incisa* at each sampling. *Nephtys incisa* were collected on a sieve after removal of a pie-shaped aliquot of bedded sediment from each chamber. Clean reference sediment, without *N. incisa*, was returned to the vacated section to maintain the integrity of the exposure chamber.

30. Suspended sediment, temperature, and salinity were measured routinely during each experiment. Dissolved oxygen (DO) concentrations were not expected to be a problem because of the large volume of the chamber and the use of an airlift. However, DO was determined once during each experiment and was never different from saturation. The worms were fed 100 mg of powdered prawn flakes per chamber per day for the duration of each experiment.

Physiological Measurements

31. At the appropriate sampling time, 15 to 20 worms were taken from the experimental conditions to assess their physiological state. Individual

respiration and ammonia excretion rates were determined prior to rinsing, drying, and weighing.

Production

32. In all experiments, juvenile worms were used so that changes in dry weight reflected only changes in growth (production). At the beginning of an experiment a subsample of individuals (10 to 15) was taken to estimate initial worm weight. The worms were quickly rinsed in deionized water, dried at 60° C for 24 hr, then weighed on a Perkin-Elmer Ad-2Z Autobalance to the nearest 1 µg. Changes in growth were computed as being the difference in dry weight from the beginning to the end of an experiment. Energy values for the tissue were determined using a wet oxidation technique in the presence of acid-dichromate mixture (Maciolek 1962).

Respiration

33. Routine rates of oxygen consumption were measured using a 3-cc syringe containing a small amount of sediment (0.5 to 0.75 cc) as a respirometer. A worm was placed in each syringe with 1.5 cc of air-equilibrated seawater. After an appropriate period of time (usually 1 to 1.5 hr), the oxygen concentration of 1 cc of the seawater was determined by injecting the sample onto the face of a radiometer-thermostated sampling cell. The syringe was then refilled to 1.5 cc, and the new oxygen concentration recalculated. This procedure was repeated up to three times per worm. A control syringe respirometer containing an appropriate amount of sediment was included in each experiment. Data evaluating the suitability of this method for determining the oxygen consumption rates of *N. incisa* are presented by Johns and Gutjahr-Gobell (1985). Energy expended during routine metabolism was considered to be the average oxygen consumption rate during the experimental period times the energy equivalent for oxygen (4.80 cal/ml) (Elliot and Davison 1975).

Ammonia excretion

34. Following their use in the respiration tests, individual *N. incisa* were placed in 6 ml of filtered seawater without sediment for approximately 3 hr to determine ammonia excretion rates. Ammonia concentrations were determined according to the technique of Bower and Holm-Hansen (1980). Calories lost per unit time as excreted ammonia were calculated by multiplying the excretion rate of an individual worm during the experimental period by the heat of formation of ammonia (0.62 cal/mg) (Elliot and Davison 1975).

Net growth efficiency

35. In addition to measuring the individual physiological parameters, net growth efficiency was also calculated for worms from the various treatments using the following formula:

$$\text{Net Growth Efficiency} = P/P + R \times 100 \quad (1)$$

where

P = amount of energy converted to new tissue

R = amount of energy used for maintenance measured via aerobic respiration

Net growth efficiency values provide insight into the degree of integration among physiological processes. It offers a time course estimate of the cumulative effects that a particular condition has had on an organism.

Field Methods

Organism collection and holding

36. *Nephtys incisa* for field studies were collected at stations REFS, 1000E, 400E, 200E, and CNTR (Table 1). Station locations were marked with

Table 1

Field Collections of *N. incisa* at the BRH Disposal Site

Collection Period	Date month/day/year	Bottom Water Temperature °C	Stations Sampled
Predisposal	04/12/83	4.5	400E, 1000E, REFS
T + 2	06/06/83	14.3	200E, 400E, 1000E, REFS
T + 8	07/19/83	18.4	200E, 400E, 1000E, REFS
T + 12	08/02/83	19.6	200E, 400E, 1000E, REFS
T + 16	09/09/83	21.3	200E, 400E, 1000E, REFS
T + 28	12/14/83	7.2	200E, 400E, 1000E, REFS
T + 40	04/15/84	0.8	200E, 400E, 1000E, REFS
T + 55	06/21/84	9.8	200E, 400E, 1000E, REFS
T + 74	10/10/84	17.1	200E, 400E, 1000E, REFS
T + 117	06/26/85	11.6	200E, 400E, 1000E, REFS

buoys for the duration of this project. While the boat was anchored, a Smith-MacIntyre grab sampler (0.1 m^2) was used to collect bottom sediments. The sediment was sieved using ambient seawater, and juveniles of the appropriate size were collected. The worms were then transferred to the laboratory and held at ambient temperature for 18 to 24 hr prior to the physiological measurements. Respiration rates of individual worms were determined using syringe respirometers containing a small amount of surficial sediment from the appropriate collection station. Following the determination of respiration rates, individual worms were placed in filtered seawater to determine ammonia excretion rates. Finally, the worms were rinsed and dried to determine dry weight. Techniques and analytical procedures used in this portion of the study were similar to those used in the laboratory phase of this study. All measurements were conducted at ambient conditions.

Exposure

37. *Nephtys incisa* field exposures via tissue residues. The purpose of exposure assessment is to determine the temporal and spatial range of exposure concentrations experienced by populations of interest. The exposure conditions present in the field for *N. incisa* were not as well characterized as they were in the laboratory studies. As a result, the description of *N. incisa* exposure to BRH material in the field is more qualitative than quantitative. First, a prediction of field exposure can be made on the basis of worm tissue residues. The relationship between exposure to BRH sediments and tissue residues was determined in a laboratory experiment. Tissue resides of PCBs as Arochlor 1254 (A1254) from worms exposed to 0-, 50-, and 100-percent BRH treatments (200 mg/ℓ suspended sediment) for 42 days in the laboratory were plotted against BRH exposure concentrations. This plot was used to estimate field exposure conditions based on tissue residues of PCBs in the field-collected worms. Inherent in this approach is the assumption that organisms in the field have bioaccumulation patterns analogous to those in the lab. Actual tissue residues in field-collected worms are given in Appendix A, Tables A-3 through A-17.

38. *Nephtys incisa* field exposures from physical data. A second analysis calculates the maximum total suspended solids concentrations from 1 m above the bottom to the sediment/water interface. This analysis assumes that the total suspended solids are comprised of BRH sediments and represent an upper bound prediction. A third analysis calculates the probable amount of

BRH sediment exposure at the sediment/water interface based upon actual contaminant concentrations for each sampling station and date. This analysis assumes that resuspension of surficial sediment is the primary source of total suspended solids at the sediment/water interface.

39. The equation used to calculate total suspended solids concentrations from the sediment/water interface up to 1 m above the bottom is described as follows:*

$$C_z = C_m\left[1 + (C_o - 1)\, e^{-kz}\right] \qquad (2)$$

where

C_z = total suspended solids concentration at distance z
C_m = total suspended solids concentration 1 m above the bottom
C_o = enrichment factor (C_z/C_m when z = 0)
-k = rate of change in total suspended solids concentration
z = distance from the bottom, m

Given the total suspended solids concentration 1 m above the bottom, the model predicts an exponential increase in suspended solids concentration at distances from 1 m above the bottom to the sediment/water interface.

40. The total suspended solids concentrations for these analyses were selected to represent average and storm conditions that were empirically determined from an in situ continuous monitoring platform deployed 1 m above the bottom at the disposal site (Bohlen and Winnick 1986, Munns et al., 1986). Enrichment factors were likewise empirically determined from acoustic profilometer data collected between the sediment/water interface and 1 m above the bottom (Bohlen and Winnick 1986, Munns et al. 1986).

Maximum upper bound estimate

41. For the purposes of the maximum upper bound analyses, it has been assumed that the exposed populations are located off the mound and aligned with the mean direction of current flow. The route of contaminant exposure is assumed to be through the transport of resuspended BRH sediments. These total suspended solids are composed of resuspended Long Island Sound sediments, as well as BRH sediment resuspended from the disposal site. Since the intent of these analyses is to create a maximum upper bound set of exposure conditions,

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* Personal Communication, John F. Paul, 1986, ERLN, USEPA.

it was assumed that the suspended solids concentration consisted in total (100 percent) of resuspended BRH sediment.

Probable exposure estimate

42. It was not within the scope of this program to provide a continuous temporal record of the percent contribution to BRH sediments to the total suspended solids load. Consequently, a second set of analyses was designed to estimate the percentage of BRH sediment that could have comprised the total suspended solids concentration at the sediment/water interface for each station and how these concentrations changed with time throughout the study. The proportions of BRH dredged material in the surficial sediments at each station and date were estimated by comparing the concentrations of selected contaminants measured in the 0- to 2-cm layer of sediment cores collected, post-disposal, at the FVP site (Appendix B, Tables B2-B13). These field concentrations were compared to the barrel concentrations to determine a percentage as follows:

$$\text{Percentage BRH Sediment} = [C - REF/BRH - REF] \times 100 \quad (3)$$

where

C = concentration of contaminant in the sediment core

REF = concentration of contaminant in REF sediment

BRH = concentration of contaminant in BRH sediment (barrel)

The percentage BRH sediment values were calculated for each station and date using the 11 different contaminants, the details of which are shown in Appendix B, Table B1. To achieve a BRH-suspended sediment concentration that reflects the surficial sediment contaminant levels for each station and date, the total suspended solids concentrations predicted for the sediment/water interface were multiplied by the estimated proportions of BRH sediment.

Chemical Methods

Analytical methods

43. The analytical methods used in this study are presented here in summary form. More detailed descriptions of the analytical methods are available in Lake, Hoffman, and Schimmel (1985). Most of these methods represent extensive modifications of USEPA standard methods developed for freshwater and

wastewater samples. It was necessary to modify these methods to analyze the types of matrices in this study. These methods were intercalibrated to ensure the quality of the data.

Organic sample preparation

44. Samples of sediment, suspended particulates, and organisms were extracted by multiple additions of increasingly less polar organic solvents using a tissue homogenizer. These mixtures were separated by centrifugation between additions; polar solvents were removed by partitioning against water; and the extracts were desulfured with activated copper powder when required. The extracts were then passed through a precolumn containing activated silica gel. Samples of both filtered and unfiltered seawater were solvent extracted in separatory funnels and the extracts saved. Foam plugs containing the dissolved organic contaminants from water samples were extracted with organic solvents. All of the above extracts were subjected to column chromatography on deactivated silica gel to separate analytical fractions and were volume reduced carefully prior to analysis.

Organic analysis

45. Electron capture gas chromatographic analyses for PCBs were conducted on a Hewlett-Packard 5840 gas chromatograph equipped with a 30-m DB-5 fused silica column. Samples were quantified against an A1254 standard because the distribution of PCB congeners in the dredged material closely matched that distribution, as did the distribution in organisms at steady state.

46. Gas chromatograph/mass spectrometric analyses were conducted with a Finnigan Model 4500 also equipped with a 30-m DB-5 fused silical capillary column. The mass spectrometer was operated through a standard Incos data system and was tuned at all times to meet USEPA quality assurance specifications.

47. All instruments were calibrated daily with the appropriate standards. The concentrations of the standards used were chosen to approximate those of the contaminants of interest, and periodic linearity checks were made to ensure the proper performance of each system. When standards were not available, response factors were calculated using mean responses of comparable standards. Blanks were carried through the procedure with each set of samples, and a reference tissue homogenate was analyzed with every 12 to 15 tissue samples.

Organic data reduction

48. As stated above, PCBs were quantified as A1254 because the sample patterns closely resembled that profile. This allowed a convenient way of reporting these data without treating the voluminous data that would have resulted from measuring some 55 congener peaks by electron capture detector. Likewise, a method was sought to summarize the PAH data. The 35 individual PAH parent and alkyl homolog compounds and groups of compounds measured in this study are listed in Appendix A. Each PAH of the same molecular weight, both parents and alkyl homologs, can be summed to yield nine PAH parent sums and five alkyl homolog sums. Although useful, this only reduced the data to 14 PAH variables, which was not sufficient. Since the distribution of PAHs differed greatly in both quantity and quality between Long Island Sound sediments and the BRH dredged material, statistics were sought which would retain significant quantitative and qualitative information.

49. The quantitative statistic chosen was the simple SUM of all measured PAHs, and a qualitative descriptor was chosen by analogy with the center of mass concept from elementary physics and called a centroid (CENT). In this case, CENT describes the "center of mass" of the PAH distribution and is in units of molecular weight. It is the concentration-weighted average molecular weight of any particular PAH distribution. Using this statistic, one is able to readily distinguish two different sources of PAH distributions--one with predominant heavy molecular weight pyrogenic compounds, and one with more lighter molecular weight petrogenic compounds. These distributions are typically found in Long Island Sound at REFS and at BRH, respectively. A major value of this statistic is that it enables one to readily distinguish these two sources when their concentrations are nearly equal. The formulas for calculating these are shown in Appendix A (Tables A1 and A2).

Inorganic sample preparation

50. Sediment was prepared for inorganic analysis by elution at room temperature with 2N HNO_3. The samples were filtered through Whatman No. 2 filter paper. Organisms were totally digested in concentrated HNO_3 at 60° C and filtered through Whatman No. 2 filter paper.

51. Cadmium, nickel, lead, and copper were concentrated and separated from both the unfiltered and filtered seawater fractions by coprecipitation (Boyle and Edmond 1975). The remaining metals (chromium, iron, manganese, and zinc) were analyzed by heated graphite atomization atomic absorption (HGA-AA)

via direct injection. Samples of suspended particulates on Nucleopore (0.45-μ) filters were eluted with 2N HNO_3 and analyzed by HGA-AA.

Inorganic analysis

52. All flame atomization atomic absorption (FA-AA) was conducted with a Perkin-Elmer (Model 5000) atomic absorption spectrophotometer. All HGA-AA determinations were conducted with Perkin-Elmer Model 500 or 2100 HGA units coupled to Perkin-Elmer Model 5000 or 603 AA instruments, respectively. The Model 5000 AA was retrofitted with a Zeeman HGA background correction unit, and the Model 603 was equipped with a D2 arc background correction system.

53. The FA-AA and HGA-AA instrument operating conditions are similar to those described in "Methods for Chemical Analysis of Water and Wastes" (USEPA 1979) and those in the manufacturer's reference manuals. The AA instruments were calibrated each time samples were analyzed for a given element. Sample extracts were analyzed a minimum of twice to determine signal reproducibility. Quality assurance checks, conducted after every 15 samples, were analyzed by the method of standard addition and by analyzing one procedural blank.

Contaminant selection

54. Chemical analyses performed in this study characterize the organic and inorganic constituents in the dredged material, provide information on the laboratory and field exposure environments, provide insight into the processes governing contaminant movement within and between environmental compartments, and determine which contaminants were accumulated by organisms. Historically, bulk sediment analyses have been used to characterize dredged material. More recently, acute toxicity bioassays and bioaccumulation have been used in conjunction with sediment chemistry to evaluate the potential for unacceptable adverse impacts. In this study, bioavailability was determined by examining the types and distributions of contaminants that bioaccumulated in laboratory studies (Rogerson, Schimmel, and Hoffman 1985). Based upon the contaminant profile for the dredged material and residue data, the contaminants selected for detailed analyses throughout the study included PCBs, PAHs, the pesticide Ethylan, and eight metals.

55. A representative subset of chemicals was selected for discussion throughout the study. The criteria used in selecting this subset included chemical properties, contaminant representativeness and behavior in various compartments, and statistical analyses of the distributions of the complete suite of chemicals analyzed in the program.

56. Multivariate clustering analyses were performed on the chemical data in an attempt to define groups or clusters of chemicals which behaved in a statistically similar manner. No assumptions were made concerning the behavior, interactions, or dynamics of chemicals between compartments; therefore, each compartment was analyzed separately. Five compartments were identified from field and laboratory data for statistical analysis. Of these, the surficial sediments and the unfiltered, particulate, and dissolved water column fractions described exposure conditions experienced by infaunal and pelagic organisms. The remaining compartment consisted of tissue residues in organisms.

57. The data were further partitioned into inorganic and organic analyses. The inorganic analyses generally consisted of 8 variables while the organic analyses contained 61 variables. The clusters of chemicals identified through the statistical analyses agreed well with those contaminants selected based on chemical properties and environmental behavior. The subset of chemicals selected as representative included six organic compounds,four metals, and two summary statistics.

Statistical Analysis Methods

58. The primary objective of the FVP was to compare laboratory and field responses under similar exposure conditions. Presented as a hypothesis, the quantitative exposure-response relationship derived from the laboratory studies would not be expected to differ significantly from a similar relationship developed from the field. The assumption implicit in this hypothesis is that the exposure conditions in the laboratory and field are analogous and can be defined in the same terms and to the same level of resolution. Because of the highly dynamic temporal and spatial conditions in the field, the exposure environment can only be given boundaries and not assigned specific values as is the case for laboratory studies. Consequently, the degree to which laboratory exposure-response relationships concur with those derived from field data can only be described qualitatively. That does not preclude the use of inferential statistical procedures to explore those laboratory and field relationships for which the appropriate quantitative information is available. However, the nature of this project was such that descriptive and exploratory statistics were often the most appropriate techniques to illustrate relations

and trends. Simple graphic representations of variable were all that was necessary to illustrate a relationship. In addition, multivariate techniques, such as cluster analysis, were the most appropriate techniques to elucidate more complex relationships between groups of selected variables.

59. Prior to making comparisons between laboratory and field effects, it was necessary to establish whether field exposure boundaries were similar to those measured in the laboratory. Assuming tissue residue and exposure are closely related, this was accomplished by examining the tissue residues of all worms from laboratory and field exposures together, independent of exposure concentration or station location and date. An agglomerative hierarchical cluster analysis was performed on the 10 selected chemical contaminants and the two summary statistics using the SAS cluster procedure (SAS 1985) to establish which tissue residues, among all the laboratory treatments and field stations, were most similar. The clustering procedure used was the average linkage method which uses unweighted pair-groups with arithmetic averages on squared distances between samples. This procedure ensured that each variable was weighted equally, even if its absolute value was orders of magnitude different from another variable.

60. The relationship between bioenergetic and tissue residue values was determined by regressing the values for the endpoints against the corresponding mean tissue residue (Snedecor and Cochran 1980). This procedure was completed individually for each of the 10 selected chemical contaminants and the two summary statistics.

PART III: RESULTS

Laboratory Results

Exposure

61. *Nephtys incisa* system monitoring. During the *N. incisa* laboratory experiments for bioenergetics, the exposure system was monitored for total suspended sediments (Table 2). In general, the exposure system maintained the suspended sediment concentrations close to the nominal 200 mg/ℓ. Temperature and salinity values were stable at approximately 20° C and 30 g/kg, respectively. Dissolved oxygen concentrations were checked once during each experiment and were never different from saturation.

Table 2

Measured Total Suspended Sediment Concentrations (Dry Weight) in the Exposure System Used for *N. incisa*

Treatment % BRH	Concentration Suspended Sediment* mg/ℓ
Experiments 1 and 2	
0	167 ± 58
25	169 ± 18
50	181 ± 20
75	194 ± 17
100	199 ± 57
Experiment 3	
0	203 ± 24
50	185 ± 21
100	183 ± 24
Experiment 4	
0	201 ± 23
50	184 ± 19
100	190 ± 21

* Mean ± 1 standard deviation (S.D.)

62. *Nephtys incisa* chemical monitoring. During the 42-day bioaccumulation experiment, seawater and *N. incisa* from the exposure chambers were sampled for chemical analysis. Seawater chemical monitoring data are presented in Table 3. The dosing system malfunctioned for 2 days, spilling

Table 3

Chemical Analysis of Seawater in Exposure Chambers of the Bioenergetics Experiment Exposing *N. incisa* to BRH Sediment

Experiment Day	Treatment % BRH	Total PCB ng/ℓ as A1254	Total Metals µg/ℓ		
			Copper	Cadmium	Chromium
3	100	NS*	407	5.4	245
	50		256	3.2	159
	0		15	0.1	15
6	100	1,170	NS	NS	NS
	50	590			
	0	79			
18**	100	340	307	3.6	181
	50	510	208	3.5	125
	0	700	134	2.2	89
32	100	NS	357	5.0	203
	50		171	2.6	106
	0		15	0.1	16
42	100	1,920	NS	NS	NS
	50	980			
	0	12			

* Not sampled.

** Dosing system malfunctioned for 2 days, spilling BRH sediments into all treatments.

BRH sediments into all treatments. The day 18 chemistry samples were taken during this period. The problem was corrected and, for the remainder of the test, the system performed normally. The chemistry data confirm that *N. incisa* received a graded exposure to BRH sediments.

63. Chemical analysis of test sediments. The contaminant-specific analysis of the BRH and REF sediments is presented in summary form in Table 4 for the representative subset of chemical compounds discussed in this report.

Table 4

Concentrations of the 10 Selected Contaminants and 2 Summary Statistics for Both BRH and REF Sediments (Means ± Standard Deviations)

Chemical Compound	Sediment* BRH	REF
Phenanthrene	5,000 ± 1,800 (15)**	85 ± 17 (12)
Sum of 178 alkyl homologs	29,000 ± 8,300 (15)	170 ± 26 (12)
Fluoranthene	6,300 ± 1,300 (15)	240 ± 33 (12)
Benzo(a)pyrene	3,900 ± 970 (15)	250 ± 28 (12)
Ethylan	4,000 ± 820 (15)	0 ± - (12)
PCB as A1254	6,400 ± 840 (15)	39 ± 4 (12)
Sum of PAHs	142,000 ± 30,000 (15)	4,500 ± 510 (12)
CENT of PAHs	232.8 ± 1.7 (15)	249.2 ± 1.7 (12)
Copper	2,900 ± 310 (18)	60 ± 3 (15)
Cadmium	24 ± 0.6 (18)	0.23 ± 0.04 (15)
Chromium	1,480 ± 83 (18)	50 ± 15 (15)
Iron	31,000 ± 2,800 (18)	21,000 ± 1,400 (15)

* Units are nanograms/gram dry weight for the organic compounds and the statistic SUM, micrograms/gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

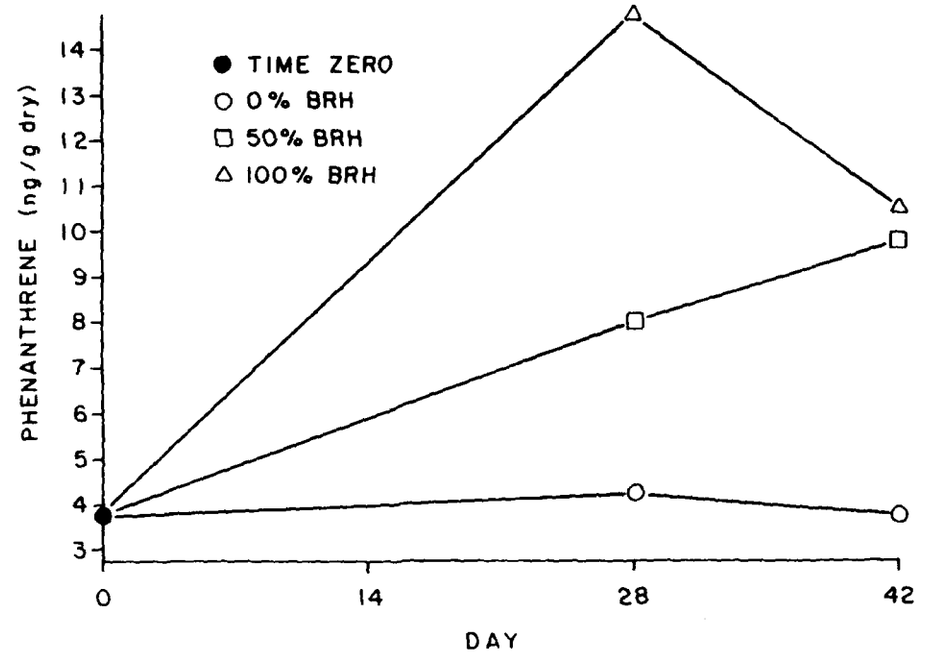
** (N) = number of replicates.

These analyses demonstrate clearly the differences in contaminant concentration between the two sediments which facilitated the tracing of these contaminants in the exposed biota.

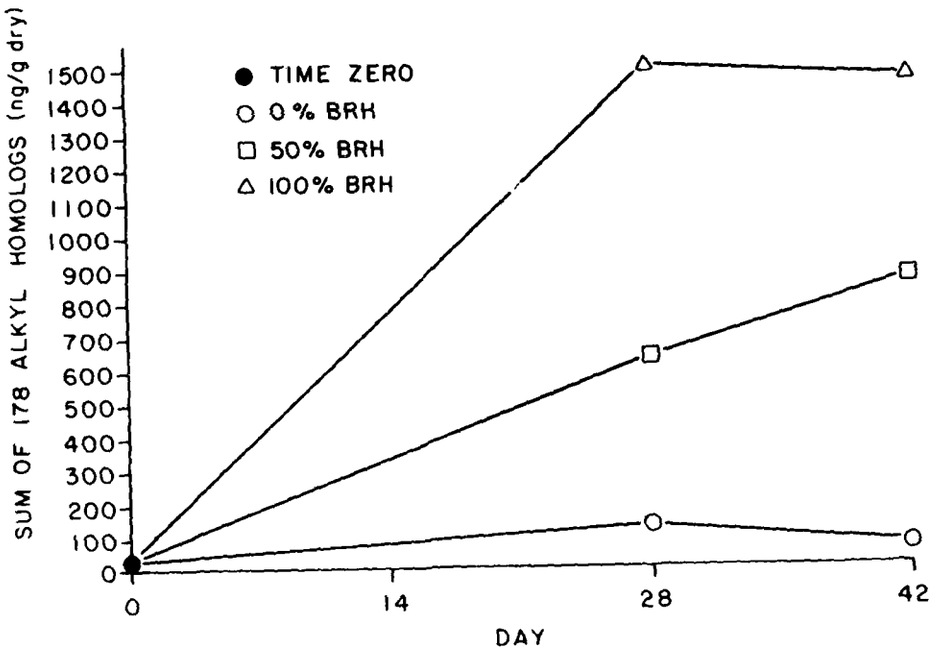
Tissue residue

64. *N. incisa* tissues from suspended sediment laboratory exposures were analyzed for a suite of organic and inorganic contaminants found in BRH sediment. These tissue residues were measured on samples from days 0, 28, and 42 of Experiment 4. The summary statistics, SUM and CENT, of the PAHs were also calculated for each of these sampling dates. The representative subsets of chemical compounds are presented graphically in Figures 6-11.

65. Although these data are not discussed in detail (see Lake et al. 1987), some general observations are made. The tissue residue concentrations of all the organic compounds increased with increasing exposure. The PAHs,

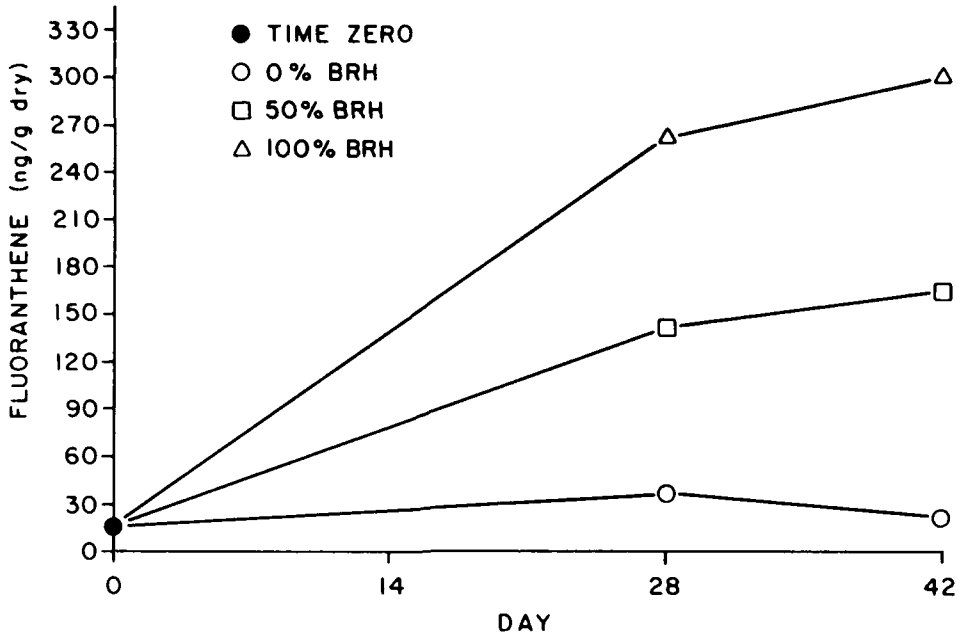


a. Phenanthrene

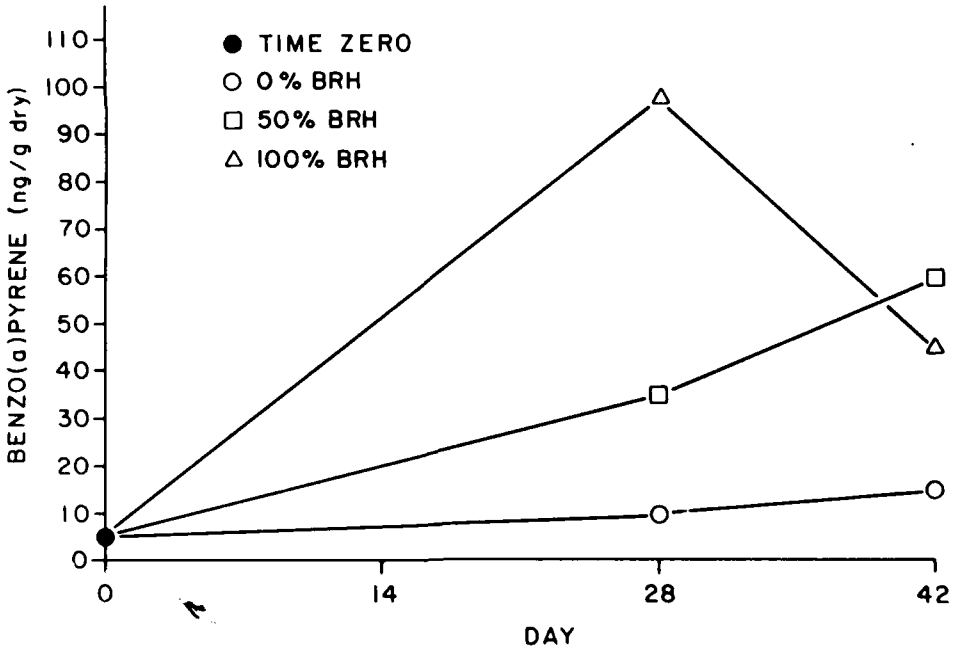


b. Alkyl homologs

Figure 6. Concentrations of phenanthrene and 178 alkyl homologs in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

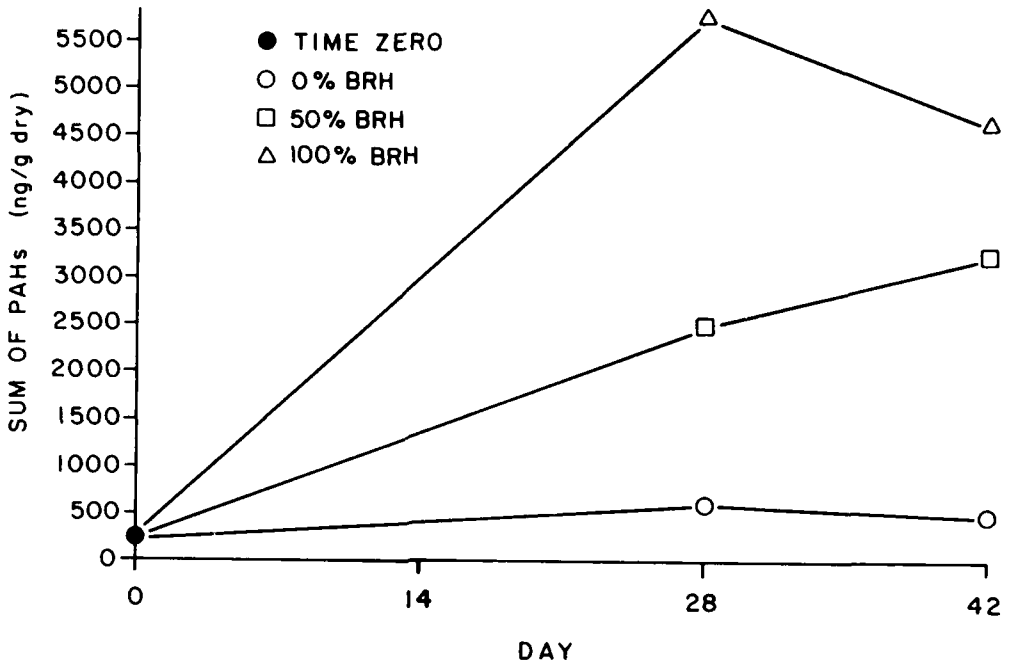


a. Fluoranthene

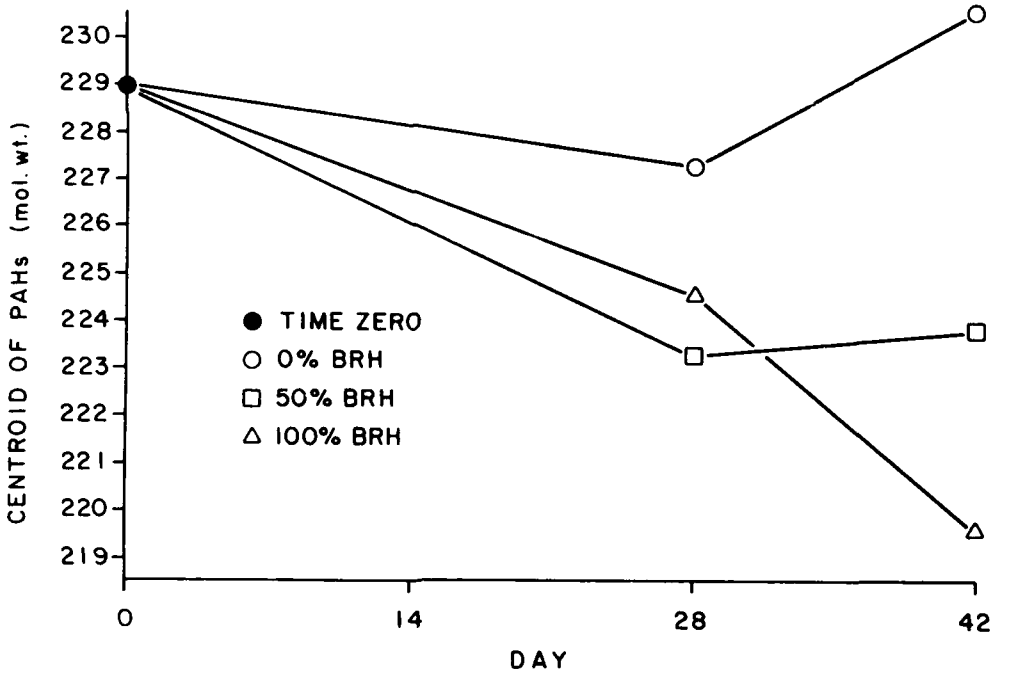


b. Benzo(a)pyrene

Figure 7. Concentrations of fluoranthene and benzo(a)pyrene in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

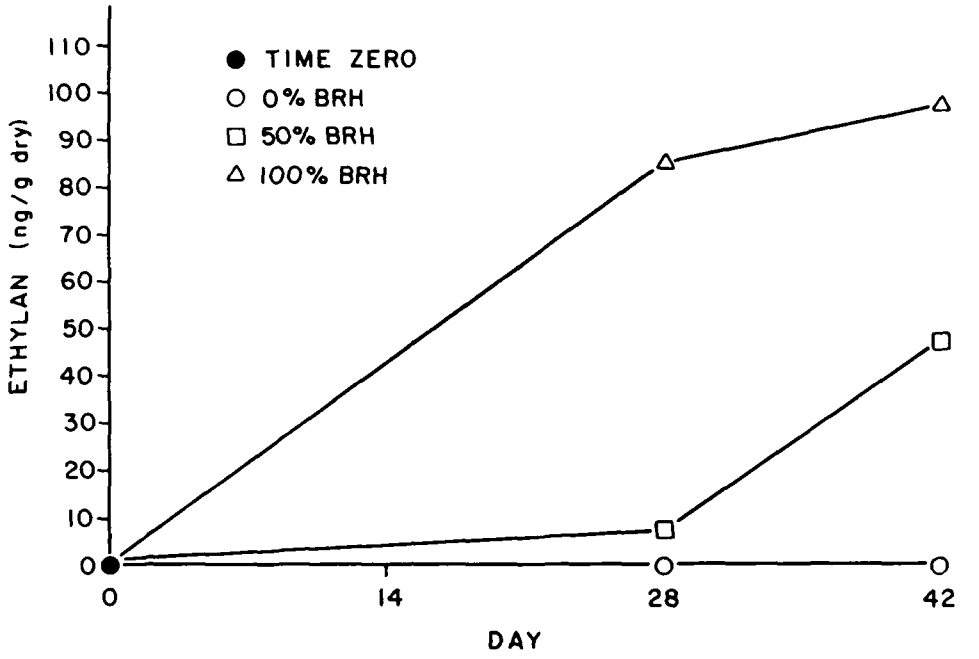


a. SUM of PAHs

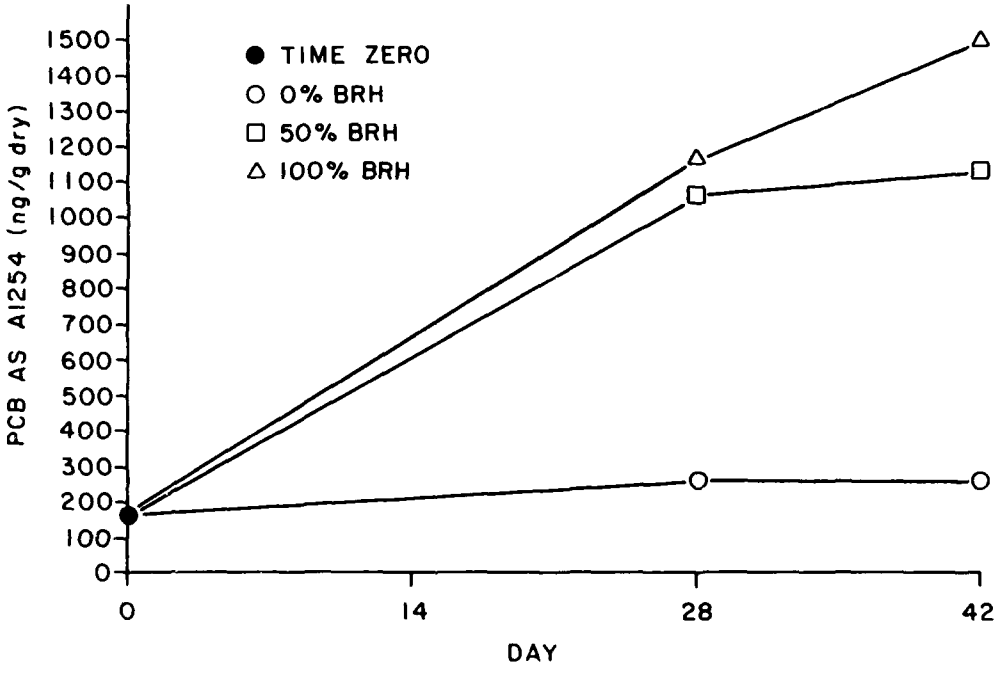


b. CENT of PAHs

Figure 8. Concentrations of the SUM of PAHs and CENT of PAHs in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

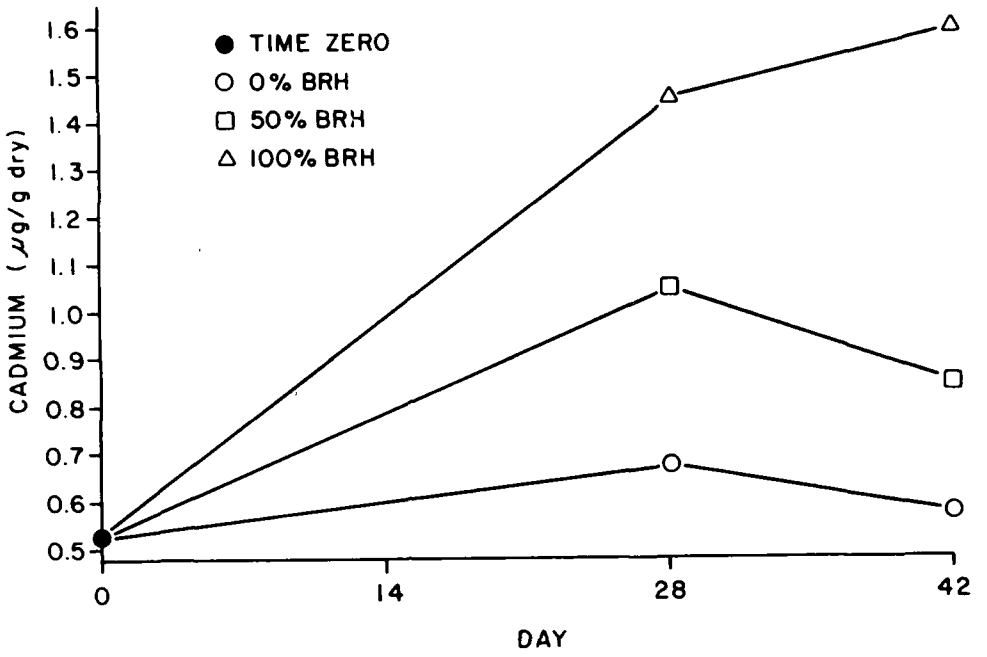


a. Ethylan

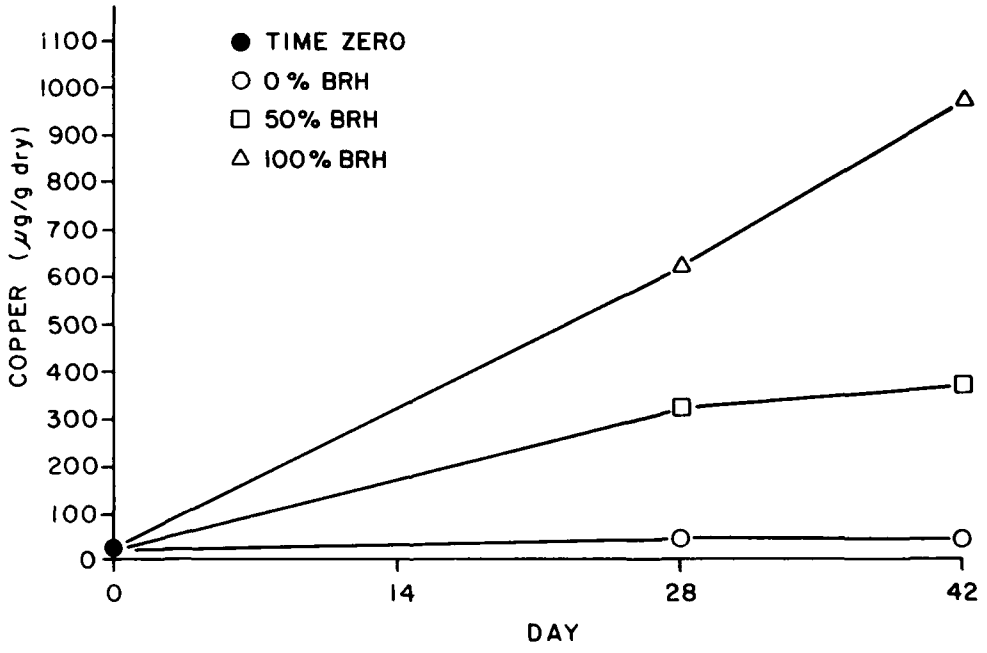


b. PCB as A1254

Figure 9. Concentrations of ethylan and PCB as A1254 in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

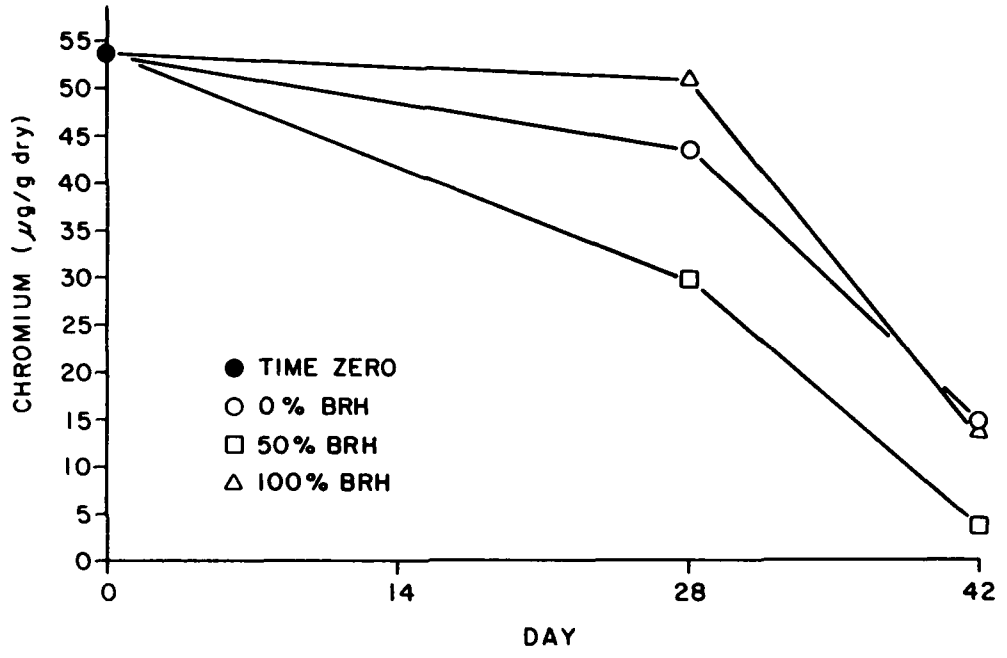


a. Cadmium

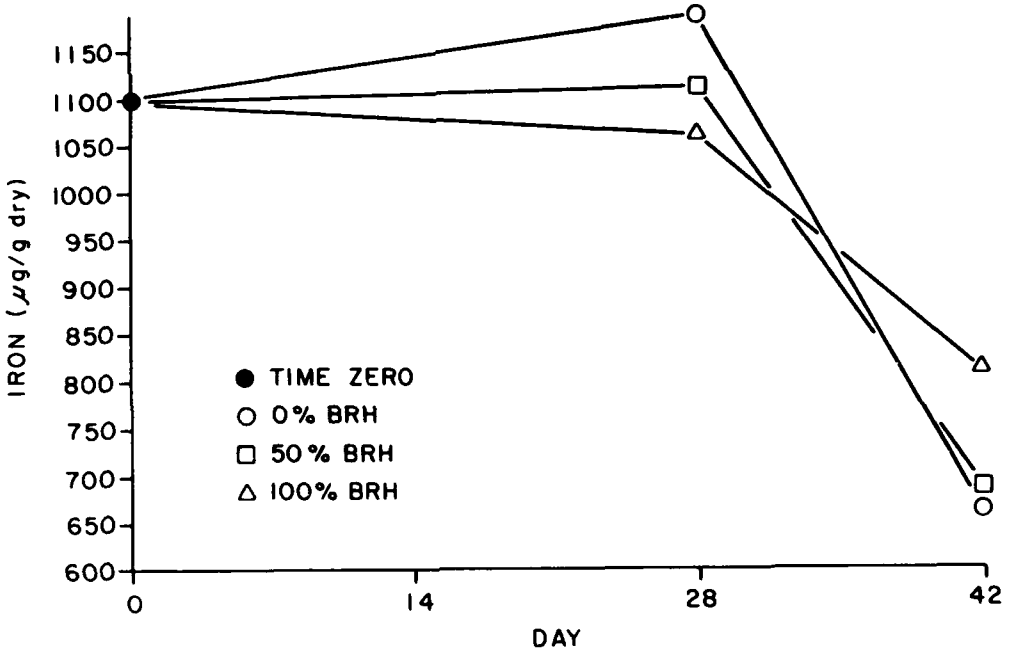


b. Copper

Figure 10. Concentrations of cadmium and copper in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days



a. Chromium



b. Iron

Figure 11. Concentrations of chromium and iron in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

with the exception of fluoranthene, reached their highest measured tissue concentrations at day 28 and exposure concentrations of 200 mg BRH/ℓ (100 percent BRH). The residue concentrations for phenanthrene and benzo(a)pyrene declined 30 percent and 50 percent, respectively, by day 42. The tissue residue concentration of PCBs reached an apparent steady state at the 100 mg BRH/ℓ (50 percent BRH) exposure by day 28, although there was a continued increase at 200 mg BRH/ℓ (100 percent BRH) at day 42. As the result of its kinetic, partitioning, and persistence properties, PCB was selected as a "tracer" for BRH material and used to relate BRH exposure conditions to tissue residues (Figure 9). Not all the inorganic compounds produced increased tissue concentrations. Copper and cadmium, which have soluble fractions in seawater, did produce elevated tissue concentrations as a consequence of increased exposure to BRH suspended sediment (Figure 10). Chromium and iron, which are bound to particulates, did not produce elevated tissue concentrations and in fact showed apparent depuration of these compounds from day 28 to 42.

Biological Energetics Laboratory Results

Production

66. In Experiment 1, exposure to concentrations of up to 200 mg/ℓ of BRH suspended particles (100 percent BRH) did not have a significant effect of the growth of *N. incisa* juveniles (Table 5). In a repeat of this experiment (Experiment 2), however, significant differences in growth were found between the treatments. Worms maintained in both the 100-percent BRH and 75-percent BRH treatments showed significant reductions in growth compared to worms maintained in the other treatments (Table 5). Juveniles from the 0-percent BRH treatment increased their weight by an average of 9 percent during the 10 days, while in the 100-percent BRH condition, worms lost an average of 15 percent of their initial weight.

67. Increasing the length of exposure had a significant effect on the growth response of *N. incisa* juveniles exposed to suspended BRH material (Tables 6 and 7). The 14-day exposure (Experiment 3) did not result in a significant difference between the treatments, although all treatments including the 0-percent BRH exhibited losses in tissue weight. Significant differences were evident, however, by day 28 (Table 6). Worms from the 0-percent BRH treatment gained an average dry weight of 6 percent while those worms from the

Table 5

Changes in Dry Weight of *N. incisa* Juveniles Exposed to Various Suspended Sediment Conditions for 14 days

Treatment % BRH	Dry Weight*, mg Initial	Final	Change in Weight Gp**	%
		Experiment 1		
0	2.030 ± 0.434	2.151 ± 0.273(20)†	A	+5
25	2.030 ± 0.434	1.955 ± 0.325(16)	A	-4
50	2.030 ± 0.434	1.741 ± 0.299(16)	A	-14
75	2.030 ± 0.434	1.756 ± 0.486(18)	A	-14
100	2.030 ± 0.434	1.783 ± 0.198(20)	A	-12
		Experiment 2		
0	1.263 ± 0.159	1.372 ± 0.217(18)	A	+9
25	1.263 ± 0.159	1.276 ± 0.205(20)	A	+1
50	1.263 ± 0.159	1.228 ± 0.279(20)	A,B	-3
75	1.263 ± 0.159	1.207 ± 0.106(20)	B	-5
100	1.263 ± 0.159	1.072 ± 0.126(20)	B	-15

* Mean ± 1 S.D.

** Gp = grouping letter. Means having the same Gp are not significantly different.

† Number of *N. incisa* used in dry weight measurements.

50- and 100-percent BRH treatments lost an average of 17 and 23 percent, respectively.

68. The pattern of tissue production found in Experiment 4 in the 0- and 100-percent BRH treatments at 28 days (Table 7) was similar to that reported after 28 days in Experiment 3 (Table 6). There were differences in the tissue production between Experiments 3 and 4 for the 50-percent BRH treatment. Tissue production decreased by 17 percent (-17 percent) in Experiment 3 but remained essentially unchanged (+1 percent) in Experiment 4. Worms maintained in the 0-percent BRH treatment increased in dry weight an average of 6 percent in Experiment 3 and 5 percent in Experiment 4, while worms exposed to 100-percent BRH decreased in dry weight an average of 23 percent (-23 percent) in Experiment 3 and 15 percent (-15 percent) in Experiment 4. The pattern of response to BRH exposure was consistent between experiments with the 0-percent BRH showing positive net growth and 100-percent BRH showing negative net growth and both treatments being significantly (P = 0.05)

Table 6

Changes in Dry Weight of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 28 days

Treatment % BRH	Dry Weight*, mg Initial	Final	Change in Weight Gp**	%
		Day 14		
0	1.139 ± 0.172	1.088 ± 0.324(18)†	A	-4
50	1.139 ± 0.172	1.053 ± 0.333(20)	A	-8
100	1.139 ± 0.172	1.073 ± 0.264(16)	A	-6
		Day 28		
0	1.139 ± 0.172	1.194 ± 0.123(16)	A	+6
50	1.139 ± 0.172	1.941 ± 0.156(14)	A,B	-17
100	1.139 ± 0.172	0.881 ± 0.168(16)	B	-23

* Mean ± 1 S.D.

** Gp = grouping letter. Means having the same Gp are not significantly different.

† Number of *N. incisa* used in dry weight measurements.

Table 7

Changes in Dry Weight of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 42 days

Treatment % BRH	Dry Weight*, mg Initial	Final	Change in Weight Gp**	%
		Day 28		
0	1.496 ± 0.271	1.571 ± 0.277(19)†	A	+5
50	1.496 ± 0.271	1.511 ± 0.071(19)	A	+1
100	1.496 ± 0.271	1.273 ± 0.110(17)	B	-15
		Day 42		
0	1.496 ± 0.271	1.800 ± 0.150(17)	A	+20
50	1.496 ± 0.271	1.263 ± 0.167(16)	B	-16
100	1.496 ± 0.271	1.081 ± 0.243(15)	C	-28

* Mean ± 1 S.D.

** Gp = grouping letter. Means having the same Gp are not significantly different.

† Number of *N. incisa* used in dry weight measurements.

different from each other. The variability in response at the 50-percent BRH exposure may have reflected a greater sensitivity of the smaller worms used in Experiment 3 (-17 percent) compared to those in Experiment 4 (+1 percent). Because of the absolute differences in the size of the worms used in the experiments, the two experiments were not combined for statistical analysis.

69. By day 42 all three treatments were significantly different from one another (Table 7). Worms maintained in the 0-percent BRH condition increased an average of 20 percent in dry weight, while individual from the 50- and 100-percent BRH treatments lost 16 and 28 percent, respectively.

Respiration rate

70. In Experiment 1, weight-specific respiration rates of those juvenile worms exposed to 100 mg/ℓ BRH suspended particles (50-percent BRH treatment) for 10 days were significantly higher than those rates for worms exposed to particles containing less than 50 mg/ℓ BRH (25-percent BRH treatment; Table 8).

71. Similar results were also found in Experiment 2, except that all treatments containing BRH material exhibited weight-specific respiration rates that were significantly higher than those rates in worms from the treatment containing only suspended REF sediment (Table 8).

72. In Experiments 3 and 4, significant differences in weight-specific respiration rates were found between the 0-percent BRH treatment and all treatments containing BRH material in the suspended phase (Tables 9 and 10). This pattern was observed at both sampling times (14 and 28 days) in Experiment 3 (Table 9) and at the 28-day sample in Experiment 4 (Table 10). The only exception to this pattern was after 42 days of exposure, when no significant difference was found between the 0- and 50-percent BRH treatments. The respiration rates of worms from both of these treatments, however, were lower than those in the 100-percent BRH treatment.

Ammonia excretion rate

73. No significant differences were found in the weight-specific ammonia excretion rate between the various treatments in Experiment 1 (Table 11). In Experiment 2, however, significantly lower weight-specific excretion rates were found at 10 days for those juveniles in treatments where the BRH level was greater than 50 percent of the total suspended particle concentration (Table 11).

Table 8

Weight-Specific Respiration Rate of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 10 days

Treatment % BRH	Respiration Rate* µℓ O_2/mg/hr	N**	Gp†
	Experiment 1		
0	1.04 ± 0.25	20	A
25	1.09 ± 0.26	16	A
50	1.52 ± 0.33	16	B
75	1.53 ± 0.43	18	B
100	1.42 ± 0.25	20	B
	Experiment 2		
0	1.12 ± 0.36	18	A
25	1.48 ± 0.41	20	B
50	1.55 ± 0.30	20	B
75	1.70 ± 0.27	20	B
100	1.65 ± 0.24	20	B

* Mean ± 1 S.D.

** N = number of *determinations*.

† Gp = grouping letter. Means having the same Gp are not significantly different.

74. In Experiment 3, no significant differences in excretion rate were found between the treatments at day 14; however, by day 28, worms from the 100-percent BRH treatment exhibited significantly lower excretion rates compared to the 0- and 50-percent BRH groups (Table 12).

75. In Experiment 4, significant differences in ammonia excretion rate were found between the treatments at both the 28- and 42-day sampling times (Table 13). At 28 days, worms from the 100-percent BRH treatment exhibited significantly lower ammonia excretion rates than did worms from the other two treatments. AT 42 days a similar pattern was found except that the worms from the 50-percent REF/50-percent BRH treatment had an intermediate response to the 0-percent REF and 100-percent BRH treatments (Table 13).

Partitioning of energy resources

76. The preceding physiological data were used to calculate the efficiency at which available energy was partitioned between growth (production

Table 9

Weight-Specific Respiration Rate of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 28 days

Treatment % BRH	Respiration Rate* µℓ O_2/mg/hr	N**	Gp†
	Day 14		
0	1.26 ± 0.34	18	A
50	1.57 ± 0.41	20	B
100	1.57 ± 0.38	16	B
	Day 28		
0	0.87 ± 0.13	16	A
50	1.45 ± 0.25	14	B
100	1.17 ± 0.28	16	B

* Mean ± 1 S.D.
** N = number of determinations.
† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 10

Weight-Specific Respiration Rate of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 42 days

Treatment % BRH	Respiration Rate* µℓ O_2/mg/hr	N**	Gp†
	Day 28		
0	1.03 ± 0.15	16	A
50	1.27 ± 0.17	14	B
100	1.31 ± 0.14	8	B
	Day 28		
0	0.92 ± 0.25	16	A
50	0.98 ± 0.31	16	A
100	1.28 ± 0.19	16	B

* Mean ± 1 S.D.
** N = number of determinations.
† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 11

Weight-Specific Ammonia Excretion Rate of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 10 days

Treatment % BRH	Excretion Rate* µg NH_4N/mg/hr	N**	Gp†
	Experiment 1		
0	0.009 ± 0.002	20	A
25	0.008 ± 0.002	16	A
50	0.008 ± 0.002	16	A
75	0.008 ± 0.004	18	A
100	0.009 ± 0.002	20	A
	Experiment 2		
0	0.008 ± 0.003	18	A
25	0.008 ± 0.003	20	A
50	0.004 ± 0.001	20	B
75	0.004 ± 0.001	20	B
100	0.004 ± 0.001	20	B

* Mean ± S.D.
** N = number of determinations.
† Gp = grouping letter. Means having the same Gp are not significantly different.

(P)) and maintenance costs (respiratory energy (R)). In the two experiments of 10 days length, no significant differences were found in maintenance costs between the treatments (Table 14). Significant differences, however, were found in the amount of energy partitioned to growth during the 10-day exposure period. In both experiments, worms from the 0-percent BRH treatment converted available energy to new tissue while worms from the 100-percent BRH treatment catabolized tissue during the experiment period (Table 14).

77. A similar pattern in energy partitioning was found in 28- and 42-day experiments (Tables 15 and 16). In both of these experiments, significant differences in the amount of energy converted to new tissue can be seen among the treatment groups with the 0-percent BRH group converting a greater amount of energy to tissue than the worms from the other treatments.

78. Comparison of the net growth efficiency of *N. incisa* juveniles from the various treatments in all experiments indicated that worms maintained in

Table 12

Weight-Specific Ammonia Excretion Rate of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 28 days

Treatment % BRH	Excretion Rate* µg NH_4N/mg/hr	N**	Gp†
	Day 14		
0	0.011 ± 0.002	18	A
50	0.009 ± 0.002	20	A
100	0.010 ± 0.004	16	A
	Day 28		
0	0.013 ± 0.004	16	A
50	0.011 ± 0.002	14	A
100	0.008 ± 0.002	16	B

* Mean ± 1 S.D.
** N = number of determinations.
† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 13

Weight-Specific Ammonia Excretion Rate of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 42 days

Treatment % BRH	Excretion Rate* µg NH_4N/mg/hr	N**	Gp†
	Day 28		
0	0.009 ± 0.004	16	A
50	0.011 ± 0.003	14	A
100	0.006 ± 0.002	8	B
	Day 42		
0	0.012 ± 0.002	16	A
50	0.009 ± 0.003	16	A,B
100	0.007 ± 0.003	16	B

* Mean ± 1 S.D.
** N = number of determinations.
† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 14

Cumulative Energy Values for Production and Maintenance Costs of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 14 Days

Treatment % BRH	Production* J**	Gp†	Respiratory Energy Expenditure* J**	Gp†
		Experiment 1		
0	+1.45 ± 0.17	A	7.12 ± 2.15	A
25	-0.90 ± 0.15	B	6.74 ± 1.54	A
50	-3.41 ± 0.31	C	8.34 ± 1.70	A
75	-3.29 ± 0.92	C	8.29 ± 2.24	A
100	-2.96 ± 0.33	C	8.10 ± 1.48	A
		Experiment 2		
0	+1.31 ± 0.21	A	4.99 ± 1.03	A
25	+0.16 ± 0.03	B	6.11 ± 1.83	A
50	-0.42 ± 0.09	C	6.11 ± 1.71	A
75	-0.67 ± 0.06	C	6.54 ± 0.97	A
100	-2.29 ± 0.27	D	5.67 ± 0.99	A

* Mean ± 1 S.D.

** J = joules.

† Gp = grouping letter. Means having the same Gp are not significantly different.

the 0-percent BRH treatment were the most efficient (range: +4.2 to +21.8 percent) at converting available energy to new tissue (Tables 17, 18, and 19). Worms maintained in 100-percent BRH were the least efficient (range: -8.2 to -60.7 percent) in all experiments. Worms maintained in combinations of REF and BRH exhibited net growth efficiencies that were intermediate to the net growth efficiencies found in the 0- and 100-percent BRH treatments.

Field Results

Exposure

79. *Nephtys incisa* exposure estimated from tissue residues. The first method used to estimate exposure conditions of *N. incisa* to BRH material in CLIS involved the laboratory-generated relationships between PCB tissue residues and BRH exposures. Using this relationship and the PCB tissue residues

Table 15

Cumulative Energy Values for Production and Maintenance Costs of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 28 Days

Treatment % BRH	Production* J**	Gp†	Respiratory Energy Expenditure* J**	Gp†
		Day 14		
0	-0.61 ± 0.18	A	10.72 ± 0.86	A
50	-1.03 ± 0.33	A	10.45 ± 1.94	A
100	-0.79 ± 0.19	A	10.25 ± 2.57	A
		Day 28		
0	+0.66 ± 0.07	A	13.89 ± 1.11	A
50	-2.38 ± 0.39	B	10.83 ± 2.25	B
100	-3.10 ± 0.59	B	10.45 ± 2.14	B

* Mean ± 1 S.D.
** J = joules.
† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 16

Cumulative Energy Values for Production and Maintenance Costs of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 42 Days

Treatment % BRH	Production* J**	Gp†	Respiratory Energy Expenditure* J**	Gp†
		Day 28		
0	+0.90 ± 0.16	A	27.28 ± 3.52	A
50	+0.18 ± 0.01	B	25.38 ± 3.26	A,B
100	-2.68 ± 0.23	C	20.90 ± 4.63	B
		Day 42		
0	+3.65 ± 0.30	A	32.70 ± 6.82	A
50	-2.80 ± 0.31	B	36.04 ± 6.18	A
100	-4.98 ± 1.12	C	25.45 ± 4.36	B

* Mean ± 1 S.D.
** J = joules.
† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 17

Net Growth Efficiency of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 10 days

Treatment % BRH	Net Growth Efficiency, %*	Gp**
	Experiment 1	
0	+16.9 ± 4.2	A
25	-12.5 ± 3.7	B
50	-35.6 ± 11.5	C
75	-32.5 ± 12.7	C
100	-28.9 ± 8.6	C
	Experiment 2	
0	+21.8 ± 6.5	A
25	+ 2.5 ± 0.8	B
50	- 7.4 ± 2.7	C
75	-11.4 ± 2.9	C
100	-60.7 ± 18.2	D

* Mean ± 1 S.D.

** Gp = grouping letter. Means having the same Gp are not significantly different.

Table 18

Net Growth Efficiency of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 28 days

Treatment % BRH	Net Growth Efficiency, %*	Gp**
	Day 14	
0	- 6.3 ± 2.4	A
50	-11.3 ± 3.3	A
100	- 8.2 ± 2.6	A
	Day 28	
0	+ 4.5 ± 1.4	A
50	-28.2 ± 7.1	B
100	-35.4 ± 10.6	B

* Mean ± 1 S.D.

** Gp = grouping letter. Means having the same Gp are not significantly different.

Table 19

Net Growth Efficiency of *N. incisa* Juveniles Exposed to BRH Suspended Sediment Conditions for 42 days

Treatment % BRH	Net Growth Efficiency, %*	Gp**
	Day 28	
0	+ 4.2 ± 1.8	A
50	+ 1.0 ± 0.3	B
100	-14.7 ± 4.9	C
	Day 42	
0	+12.3 ± 3.6	A
50	- 8.4 ± 2.1	B
100	-24.3 ± 7.3	C

* Mean ± 1 S.D.

** Gp = grouping letter. Means having the same Gp are not significantly different.

in field collected *N. incisa*, estimates of field BRH exposure concentrations were calculated. There are several assumptions in this approach: *N. incisa* provides an integrated measure of exposure; *N. incisa* tissue residues were at steady state with BRH exposure concentrations at the time of sampling; and PCBs are a good chemical marker for BRH sediments. Based on the results of the laboratory experiment, each of these assumptions seems reasonable.

80. The estimated exposures resulting from this approach are presented as milligrams/litre BRH for each station and collection date in Table 20. *Nephtys incisa* at CNTR were buried during disposal of the dredged material and did not recolonize the dredged material mound until the spring of 1984. When the worms recolonized the mound, sampling was begun. The data in Table 20 display clear spatial and temporal trends. The highest exposure estimates were in the immediate vicinity of the disposed BRH material (400E) during the summer of 1983. There was a decrease in exposure at stations 400E and 100E in 1984 and 1985.

81. *Nephtys incisa* exposure estimates from physical data. Benthic exposure at the FVP disposal site can occur through both the suspended and bedded sediments. This section describes the results of calculations of the maximum upper bound suspended sediment concentrations from 1 m above the

Table 20

Estimated Concentrations of BRH Sediment (mg/ℓ) Suspended at Sediment/Water Interface Based on PCB Concentrations in Field-Collected *N. incisa*

Date	Station			
	CNTR	400E	1000E	REFS
17 Apr 82	--	0	--	0
16 Nov 82	--	0	--	2
16 Feb 83	--	9	--	3
12 Apr 83	--	15	--	8
02 Jun 83	--	95	43	2
03 Jul 83	--	114	44	2
06 Sep 83	--	131	88	12
29 Nov 83	--	51	26	0
20 Mar 84	47	38	10	0
16 Oct 84	53	29	10	3
24 Jan 86	76	5	4	0

bottom to the sediment/water interface. This calculation is based upon the assumption that the suspended solids at the sediment/water interface consist totally of BRH sediment and that the contaminant concentrations are similar to those found in the dredged material prior to disposal.

82. Total suspended solids concentrations were measured at the FVP site at 1 m above the sediment/water interface with an in situ monitoring platform (Bohlen and Winnick 1986). Although there is considerable variation in the data through one tidal cycle, average background suspended solids were estimated to be 10 mg/ℓ, while during typical storm conditions suspended solids concentrations averaged 30 mg/ℓ for periods of 4 to 7 days (Munns et al. 1986).

83. Using an acoustic profilometer, the suspended sediment concentrations at 1 m above the bottom were found to increase exponentially to the sediment/water interface. The upper and lower limits for this increase are 10× and 1×, respectively, depending on hydrographic conditions (Bohlen and Winnick 1986). These data, in conjunction with suspended solids concentrations at the sediment/water interface.

84. For example, the suspended solids concentration under background conditions (10 mg/ℓ) would increase to 100 mg/ℓ for the 10× enrichment at the sediment/water interface, and decrease to 10 mg/ℓ for the quiescent conditions. Likewise, under storm conditions (30 mg/ℓ), sediment/water interface suspended solids concentrations would range from 300 to 30 mg/ℓ for the 10× and 1× enrichments, respectively (Figure 12). These conditions represent

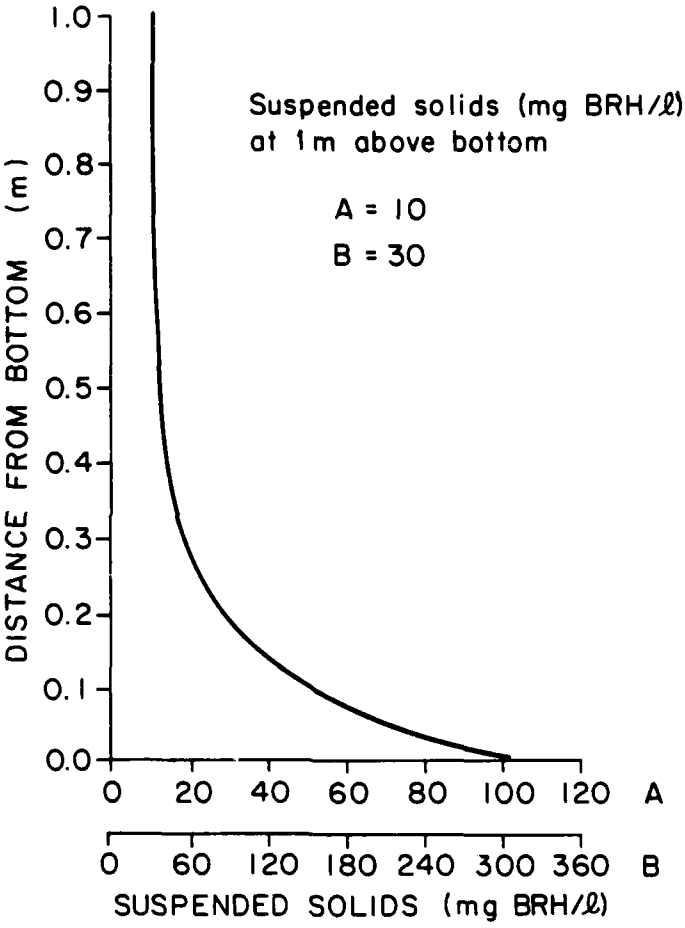


Figure 12. Suspended sediment concentrations from 1 m above the bottom to the sediment/water interface for storm and background conditions

the maximum upper bound exposures that would be expected to occur at the sediment/water interface and could be made using predisposal site characterization data.

85. A more probable estimate is provided by using contaminant concentrations present in the sediments after disposal. It is this material that

will be resuspended and transported as suspended solids to populations outside the disposal site. Assuming that resuspended surficial sediments are the source of contaminants for the suspended sediments, the maximum upper bound estimates can be adjusted to reflect the spatial and temporal changes in contaminant concentration. These changes are represented as percentages of BRH sediment in the 0- to 2-cm surface layer at stations CNTR, 200E, 400E, and 1000E from June 1983, immediately after disposal, to October 1985 (Table 21). The combination of these percentages and the total suspended

Table 21

Percent BRH Sediment in the Surficial Sediments at the FVP Disposal Site

Date	Station			
	CNTR	200E	400E	1000E
Jun 83	44.5	41.1	12.5	1.8
Jul 83	15.0	37.4	3.3	1.6
Sep 83	32.0	36.7	4.9	2.0
Dec 83	32.8	36.1	9.5	4.4
Mar 84	4.4	2.2	1.9	1.8
Jun 84	9.5	15.6	0.5	0.7
Sep 84	10.0	0.8	3.5	0.5
Oct 84	2.6	--	0.2	1.6
Dec 84	35.1	11.3	0.0	1.0
Oct 85	0.2	21.0	0.0	0.0

solids concentrations predicted for the sediment/water interface results in concentrations of BRH suspended sediments at the sediment/water interface for each station and sampling date (Table 22).

86. The sediment samples used for the percent calculations were not replicated and, therefore, no variability estimates are available. However, certain trends in the data are evident (Table 21). The percentages of BRH sediment (<50 percent) at CNTR and 200E were low compared to the barrel sediments collected predisposal. There is a gradient of BRH material that is a function of both distance from the center of the mound and of time from disposal. Black Rock Harbor sediment concentrations were highest at CNTR and 200E immediately after disposal, and decreased significantly through October

Table 22

Concentration of BRH (mg/ℓ) at the Sediment/Water Interface for Total Suspended Sediment Concentrations of 30 mg/ℓ and 10 mg/ℓ at 1 m Above the Bottom and an Enrichment of 10×*

	Station							
	CNTR		200E		400E		1000E	
Date	30	10	30	10	30	10	30	10
Jun 83	133.5	44.5	123.3	41.1	37.5	12.5	5.4	1.8
Jul 83	45.0	15.0	112.2	37.4	9.9	3.3	4.8	1.6
Sep 83	96.0	32.0	110.1	36.7	14.7	4.9	6.0	2.0
Dec 83	98.4	32.8	108.3	36.1	28.5	9.5	13.2	4.4
Mar 84	14.2	4.4	6.6	2.2	4.7	1.9	5.4	1.8
Jun 84	28.5	9.5	46.8	15.6	1.5	0.5	2.1	0.7
Sep 84	30.0	10.0	2.4	0.8	10.5	3.5	1.5	0.5
Oct 84	7.8	2.6	--	--	0.6	0.2	4.8	1.6
Dec 84	105.3	35.1	33.9	11.3	0	0	3.0	1.0
Oct 85	0.6	0.2	63.0	21.0	0	0	0	0

* BRH concentrations for the 1× enrichment can be obtained by dividing the tabular values by 10.

1984. Concentrations were elevated in December 1984 at CNTR and 200E and again in October 1985 at 200E. The BRH concentrations at 400E also decreased through time and, after December 1983, were the same as those at 1000E.

87. The 1- to 2-percent BRH sediment calculated for 1000E represents a quantitatively measured elevation above background and is supported by tissue residue data for *N. incisa*. This contamination could have resulted from the dispersion of dredged material during disposal, the errant disposal of BRH material in the vicinity of 1000E, or the continued transport of contaminated material from the disposal mound.

88. The estimates of exposure to BRH material at the sediment/water interface derived from tissue concentrations of PCB and from the maximum upper bound calculations agreed well. The exposure estimates based on the chemistry of the 0- to 2-cm surface sediments were low. If the exposure estimates based on tissue concentrations of PCB are accepted as a valid check on the exposure estimates from the physical models, it is concluded that the higher estimates of exposure are accurate. The simplest explanation is that the 0- to 2-cm

sampling procedure integrates deeper clean and surficial contaminated sediments, thus underestimating the actual exposures experienced by the worms. The data suggest that the worms were exposed to a thin surface layer of contaminated sediment.

Tissue residues

89. The tissue concentrations for the *N. incisa* collected at the CLIS site during the FVP study are presented graphically for each of the 12 selected chemical variables in Figures 13-18. The raw data shown in these figures are included in the Appendix Tables A3-A17.

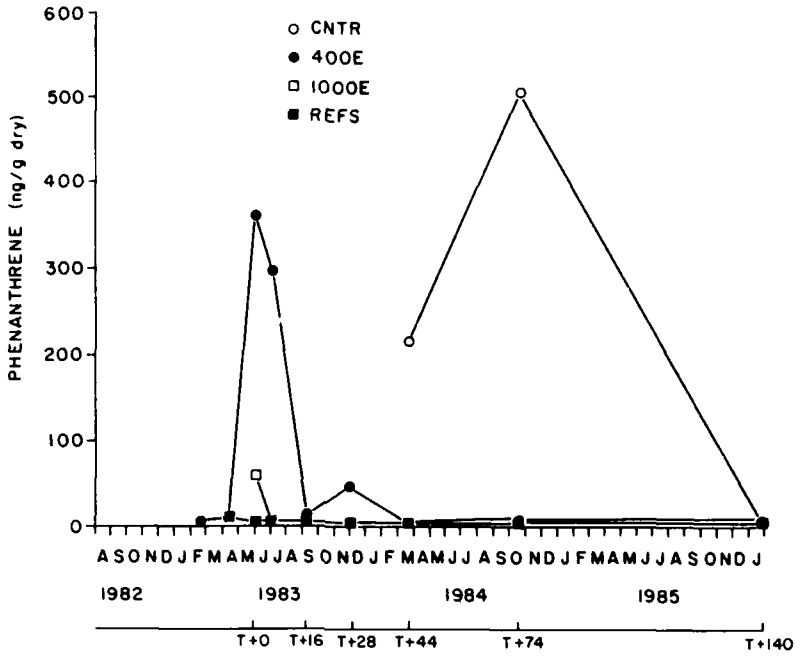
90. Clear spatial and temporal patterns of tissue concentrations of PCBs and PAHs were found. Highest tissue concentrations were determined at station 400E with lowest concentrations at station REFS. When *N. incisa* recolonized the dredged material site at station CNTR in the spring of 1984, the tissue concentrations of PCBs in these worms were comparable to those found at 400E immediately postdisposal.

91. The temporal patterns of the field tissue residues show a rapid increase in organic residue values during and immediately postdisposal at 400E and at 1000E. The PAH residues for *N. incisa* showed an increase immediately postdisposal. This was followed by a rapid decline during July and August. The phenanthrene residue value returned to background levels by September, but the higher molecular weight PAH tissue residues tended to remain at approximately 25 percent of their maximum values for an additional year. The PCB residues at 400E increased rapidly immediately after disposal and, unlike the PAHs, remained elevated through September and declined only 50 percent by December 1983. Unlike the PAHs, PCB residues increased 2.5 times REFS at 1000E postdisposal and remained elevated above REFS until October 1984. There were no clear temporal or spatial patterns for inorganic tissue residues for *N. incisa* from the field.

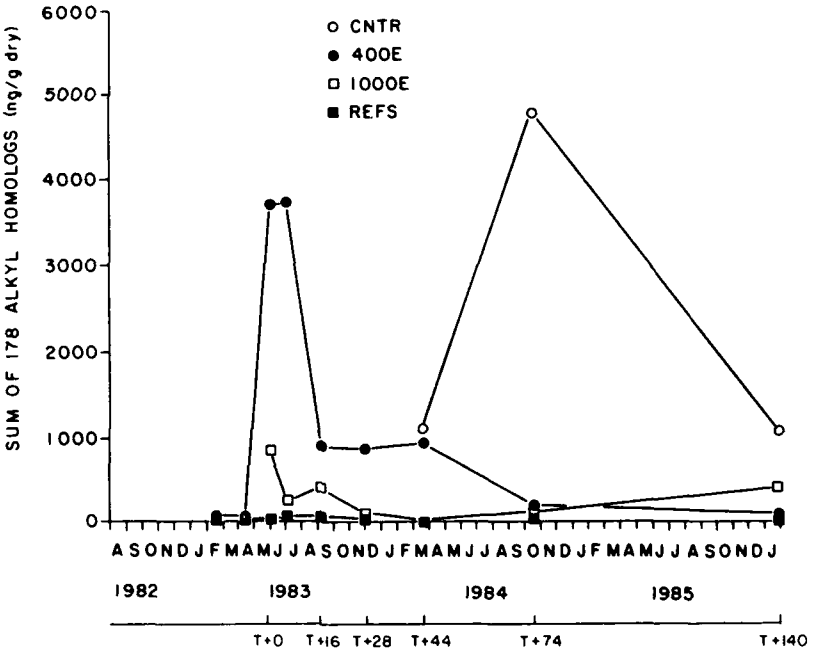
Biological Energetics Field Results

Respiration rate

92. Although limited in scope, field data collected from the various stations around the BRH disposal site for weight-specific respiration and ammonia excretion rates indicated that significant changes occurred following disposal (Tables 23 and 24).

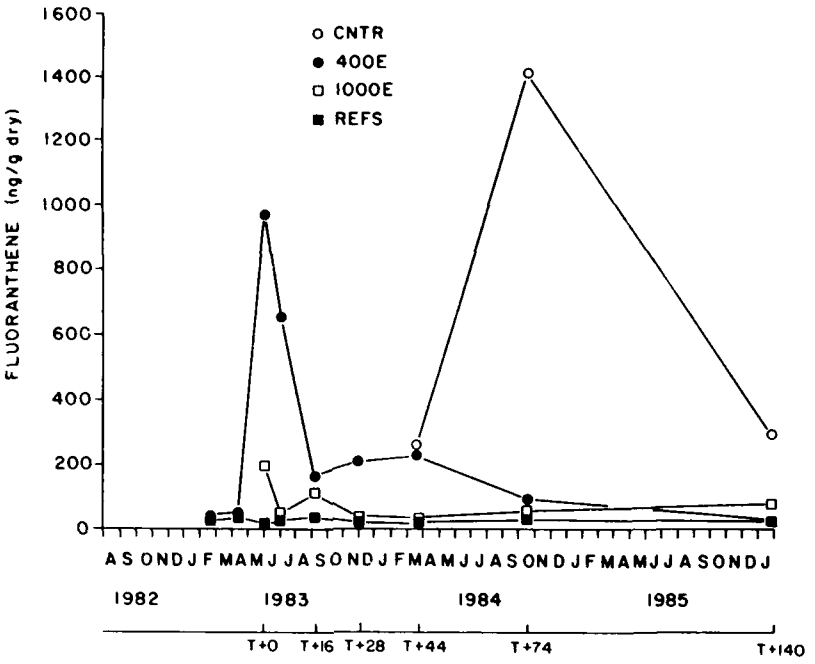


a. Phenanthrene

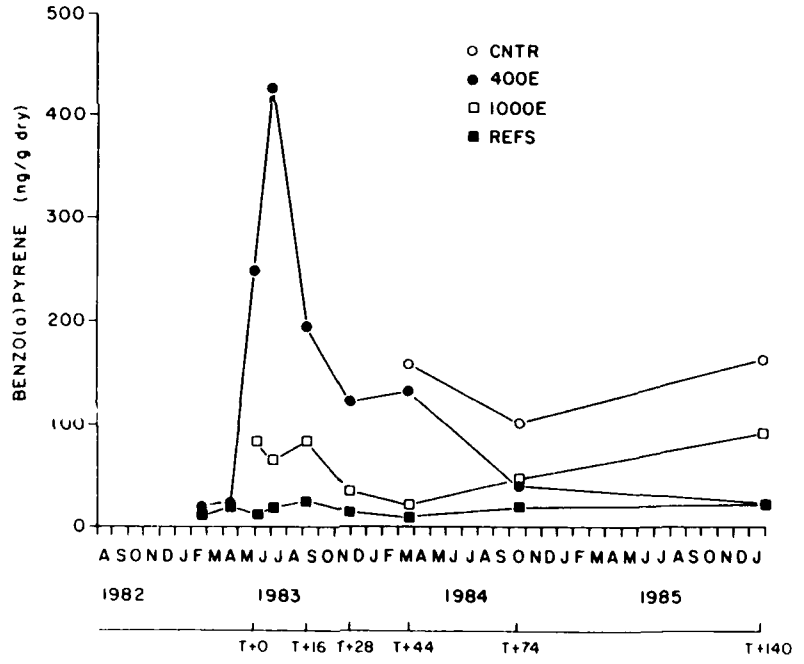


b. Alkyl homologs

Figure 13. Concentrations of phenanthrene and the 178 alkyl homologs in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

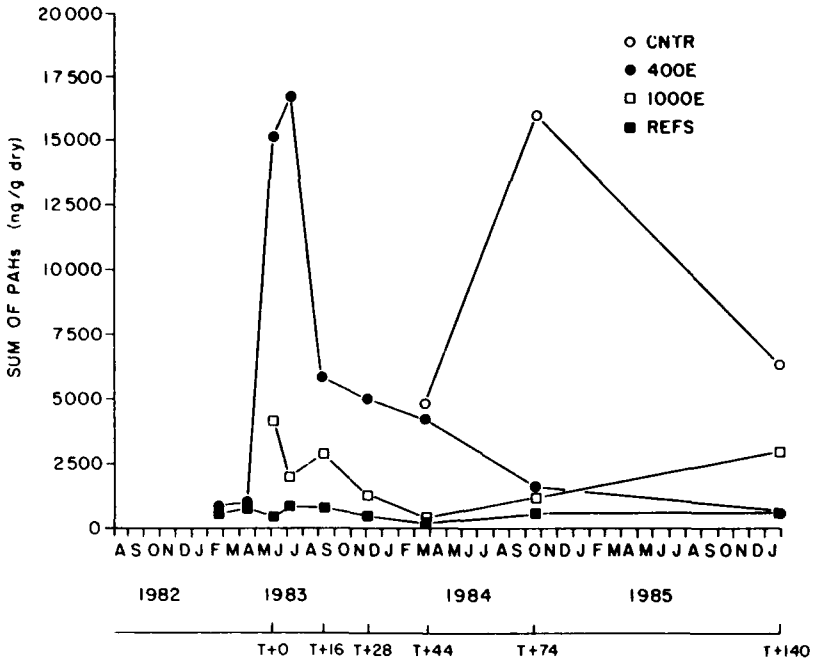


a. Fluoranthene

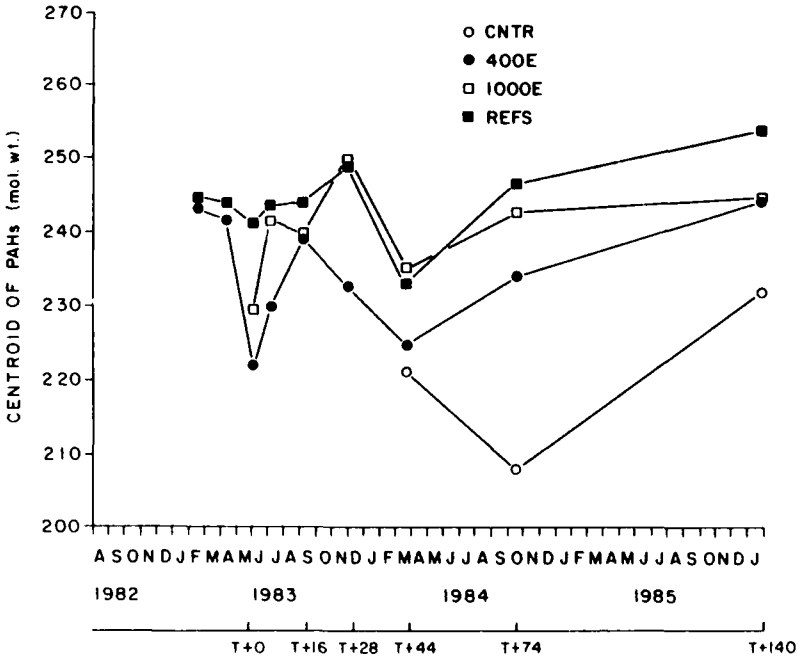


b. Benzo(a)pyrene

Figure 14. Concentrations of fluoranthene and benzo(a)pyrene in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

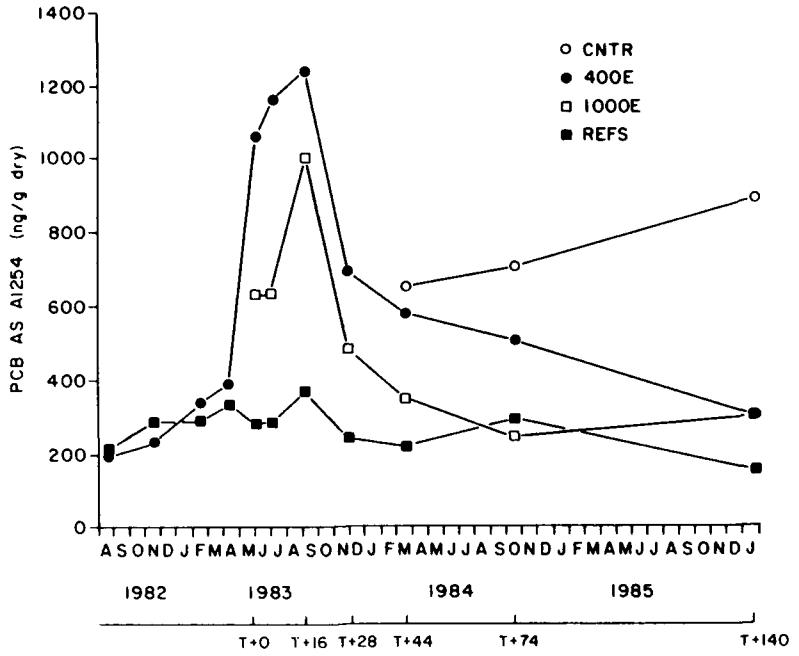


a. SUM of PAHs

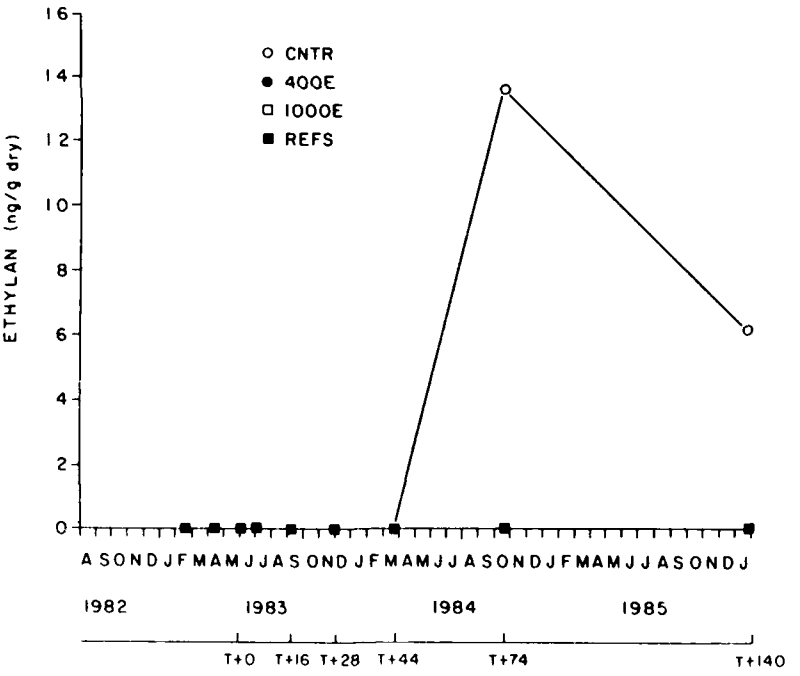


b. CENT of PAHs

Figure 15. Concentrations of the SUM of the PAHs and CENT of PAHs in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

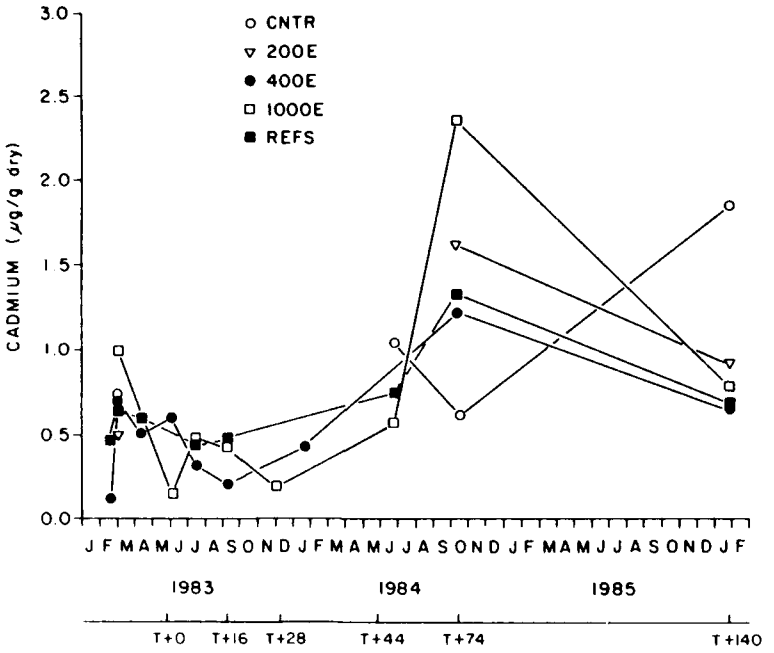


a. PCB as A1254

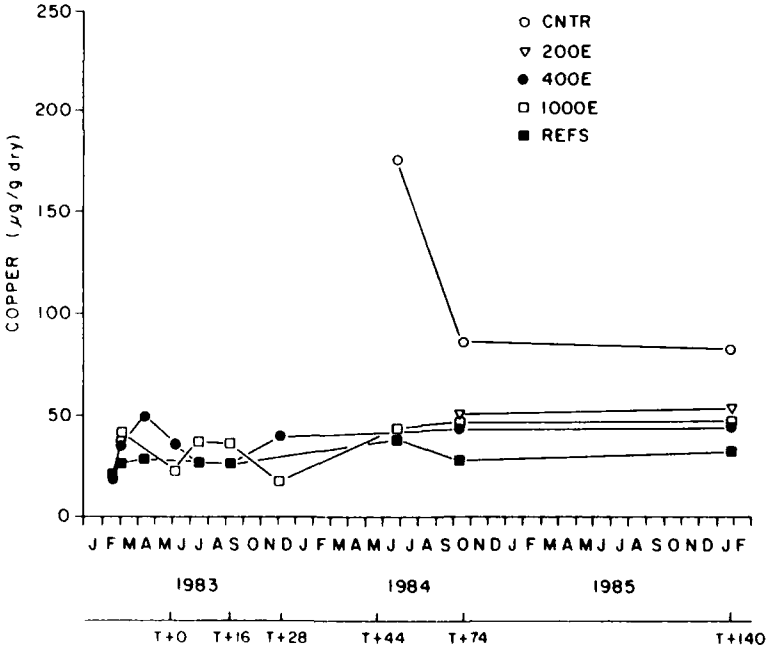


b. Ethylan

Figure 16. Concentrations of PCBs as A1254 and ethylan in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

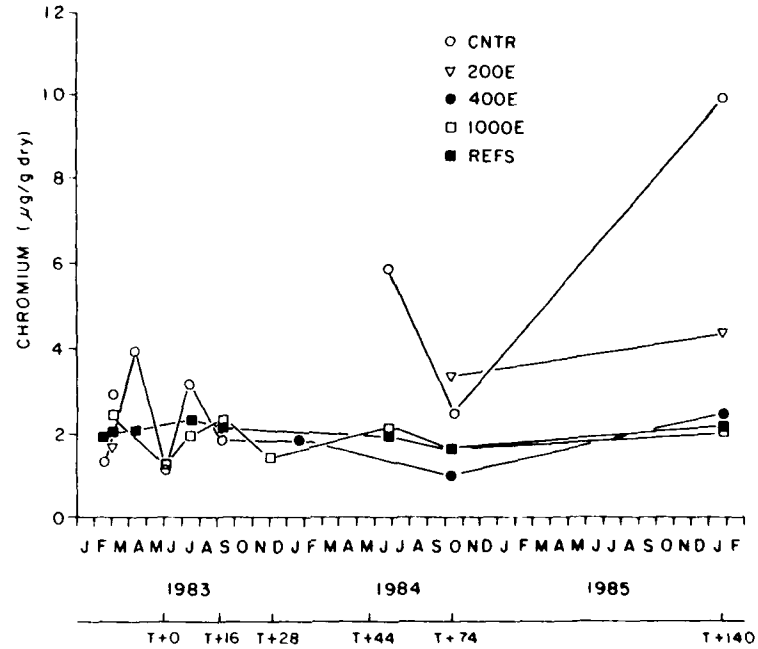


a. Cadmium

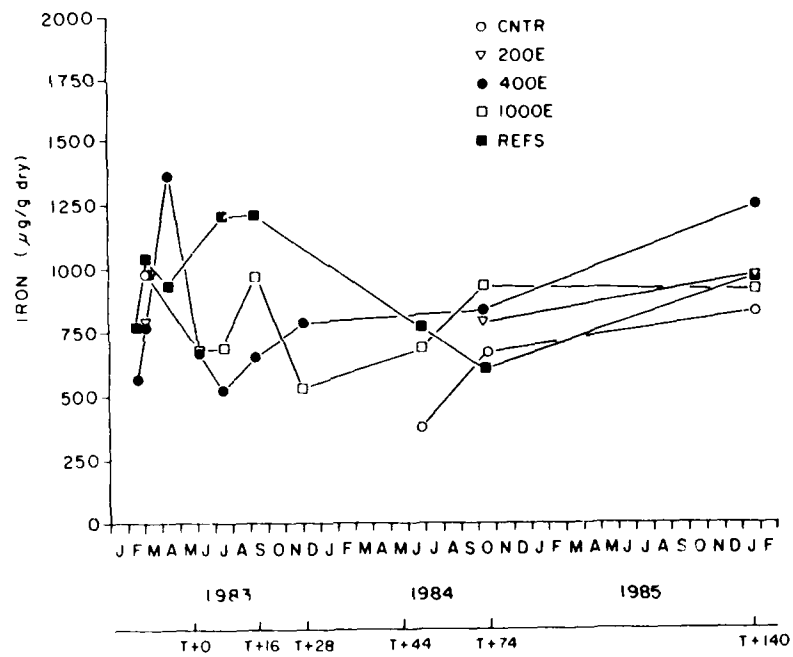


b. Copper

Figure 17. Concentrations of cadmium and copper in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates



a. Chromium



b. Iron

Figure 18. Concentrations of chromium and iron in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

Table 23

Weight-Specific Respiration Rate of *N. incisa* Juveniles Collected from Various Stations at the BRH Disposal Site

Time*	Station	Respiration Rate** µl O_2/mg/hr	Gp†
Predisposal	REFS	0.70 ± 0.28	A
	1000E	0.75 ± 0.36	A
	400E	0.88 ± 0.31	A
	200E	--	
T + 2	REFS	1.18 ± 0.39	A
	1000E	1.39 ± 0.44	A
	400E	0.92 ± 0.35	B
	200E	0.72 ± 0.29	B
T + 8	REFS	1.47 ± 0.52	A
	1000E	1.51 ± 0.34	A
	400E	1.06 ± 0.32	B
	200E	0.88 ± 0.24	C
T + 12	REFS	1.30 ± 0.25	A
	1000E	1.22 ± 0.28	A
	400E	0.86 ± 0.32	B
	200E	0.70 ± 0.20	B
T + 16	REFS	1.62 ± 0.49	A
	1000E	1.43 ± 0.46	A
	400E	1.03 ± 0.26	B
	200E	0.96 ± 0.34	B
T + 28	REFS	0.48 ± 0.14	A
	1000E	0.61 ± 0.20	A
	400E	0.52 ± 0.19	A
	200E	0.58 ± 0.16	A
T + 40	REFS	0.52 ± 0.18	A
	1000E	0.57 ± 0.22	A
	400E	0.63 ± 0.28	A
	200E	0.47 ± 0.31	A

(Continued)

* Time intervals are in weeks postdisposal.

** Mean ± 1 S.D.

† Gp = grouping letter. Means with the same Gp are not significantly different.

Table 23 (Concluded)

Time	Station	Respiration Rate µℓ O_2/mg/hr	Gp
T + 55	REFS	1.00 ± 0.35	A
	1000E	0.87 ± 0.37	A
	400E	0.93 ± 0.41	A
	200E	0.80 ± 0.20	A
T + 74	REFS	1.25 ± 0.38	A
	1000E	1.45 ± 0.46	A
	400E	0.86 ± 0.30	B
	200E	0.75 ± 0.28	B
T + 117	REFS	1.36 ± 0.24	A
	1000E	1.55 ± 0.39	A
	400E	1.20 ± 0.38	A,B
	200E	0.94 ± 0.34	B

93. Weight-specific respiration rate was not significantly different in worms at the various stations prior to the disposal of BRH material (Table 23), based on a single sampling period. Following disposal, significant changes in respiration rate occurred between the worms from the various sampling stations. Following disposal, a significant reduction in respiration rate was seen in worms collected from the two stations closest to the center of the disposal mound (200E and 400E stations). This pattern was seen immediately after disposal (T + 2) and persisted through September (T + 16) while the water temperatures were above 12° C. This same response pattern reappeared in the summer of 1984 (T + 74) and 1985 (T + 117) after being absent during periods of reduced water temperature.

94. In general, the weight-specific respiration rates of worms from all sampling stations appear to follow a seasonal pattern. During the months when water temperatures are warmer (e.g., T + 2, T + 8, T + 12, T + 16, T + 74, T + 117) the oxygen consumption rates are higher than in months in which water temperatures are cooler (e.g., T + 28, T + 40, T + 55). In addition, statistically significant differences in respiration rate between worms from the disposal site sampling stations appear to occur during the sampling times when the water temperature is above 11° C.

Table 24

Weight-Specific Ammonia Excretion Rate of *N. incisa* Juveniles Collected from Various Stations at the BRH Disposal Site

Time*	Station	Excretion Rate** µg NH_4N/mg/hr	Gp†
Predisposal	REFS	0.008 ± 0.004	A
	1000E	0.007 ± 0.002	A
	400E	0.009 ± 0.004	A
	200E	--	
T + 2	REFS	0.013 ± 0.004	A
	1000E	0.011 ± 0.003	A,B
	400E	0.010 ± 0.004	B,C
	200E	0.008 ± 0.002	C
T + 8	REFS	0.014 ± 0.003	A
	1000E	0.012 ± 0.002	A,B
	400E	0.009 ± 0.002	B
	200E	0.010 ± 0.004	B
T + 12	REFS	0.012 ± 0.005	A
	1000E	0.011 ± 0.004	A
	400E	0.009 ± 0.004	A,B
	200E	0.006 ± 0.003	B
T + 16	REFS	0.021 ± 0.008	A
	1000E	0.016 ± 0.006	A
	400E	0.009 ± 0.004	B
	200E	0.012 ± 0.003	B
T + 28	REFS	0.006 ± 0.003	A
	1000E	0.006 ± 0.004	A
	400E	0.007 ± 0.003	A
	200E	0.007 ± 0.003	A
T + 40	REFS	0.007 ± 0.002	A
	1000E	0.009 ± 0.003	A
	400E	0.006 ± 0.003	A
	200E	0.006 ± 0.004	A

(Continued)

* Time intervals are in weeks postdisposal.

** Mean ± 1 S.D.

† Gp = grouping letter. Means having the same Gp are not significantly different.

Table 24 (Concluded)

Time	Station	Excretion Rate µg NH_4N/mg/hr	Gp
T + 55	REFS	0.012 ± 0.002	A
	1000E	0.009 ± 0.003	A
	400E	0.011 ± 0.004	A
	200E	0.009 ± 0.002	A
T + 74	REFS	0.014 ± 0.004	A
	1000E	0.016 ± 0.004	A
	400E	0.009 ± 0.003	B
	200E	0.010 ± 0.005	A,B
T + 117	REFS	0.015 ± 0.004	A
	1000E	0.016 ± 0.003	A
	400E	0.010 ± 0.003	B
	200E	0.008 ± 0.002	B

Ammonia excretion rate

95. As with weight-specific respiration rate, statistically significant changes in ammonia excretion rate were observed in worms from several sampling stations following the disposal of BRH material (Table 24). Two weeks following disposal, significant reductions in excretion rate can be seen for worms collected from the 200E and 400E sampling stations when compared to the excretion rate of worms from the South Reference site.

96. During the remainder of the sampling period, weight-specific ammonia excretion rates were lower in worms from the 200E and 400E sampling stations compared to worms from the 1000E and REFS sites. A seasonal cycle was found for ammonia excretion rate, with rates being greater in worms collected in those months when the water temperature was above 11° C.

Laboratory-to-Field Comparisons

97. Laboratory-to-field relationships are presented for both tissue residue data and the bioenergetics endpoints. The approach used was to define these relationships using exposure as the integrator. First, it was necessary to establish when exposure conditions were similar in the laboratory and the field. This was done by comparing the tissue residue values and analyzing the physical data under the assumption that comparable tissue residues reflect

analogous exposure to BRH contaminants. Calculation of exposure conditions was followed by comparing the exposure-response relationships for the bioenergetics endpoints in the laboratory to those developed from field bioenergetics data and calculated suspended sediment exposures estimated from physical data.

98. Tissue residue data for 12 representative chemical variables were analyzed statistically by cluster analysis to identify distinctive patterns of association between the laboratory and field. The cluster analysis revealed no consistent clustering of the laboratory data separate from the field data. This indicates that the range of residue data from the laboratory overlapped that from the field and that the exposure environments were similar. This interpretation is supported by field exposure estimates derived from physical data that predict the maximum concentrations of BRH suspended sediment at the sediment/water interface to range from 44.5 to 100 mg/ℓ under conditions of maximum chronic exposure.

99. The laboratory bioenergetics data (42-day exposures) indicate a clear exposure-response relationship for all the endpoints examined (Figure 19). Except for respiration, the response was a decrease in the physiological variable. In general, the threshold concentration for these responses was in the range of 50 to 100 mg/ℓ of BRH suspended sediments, though for net growth efficiency and cumulative energy for production, EC50 values of 30 mg/ℓ were estimated. Examination of the field bioenergetics data indicated statistically significant reductions in the values of physiological measurements of worms collected from the 200E and 400E stations as compared with worms from 1000E and REFS stations. These differences were observed only when the ambient temperature was greater than 11° C.

100. Calculations of BRH suspended sediment exposures at 200E ranged from 21 to 41 mg/ℓ (Table 22), indicating concurrence with the exposures determined to cause an impact on the bioenergetic responses in the laboratory. Predications of BRH sediment exposures at 400E ranged from 0 to 12.5 mg/ℓ, which is below the response threshold for any of the bioenergetic responses measured in the laboratory; yet, statistically significant effects were reported in the field for the bioenergetics endpoints (Tables 23 and 24). This apparent inconsistency may result from limitations in the sampling design employed for selecting the proper depth of the horizon for contaminant analysis in the sediments. The immediate postdisposal depth of BRH sediment at 400E was estimated from visual observations to range from 0.1 to 0.5 cm while the

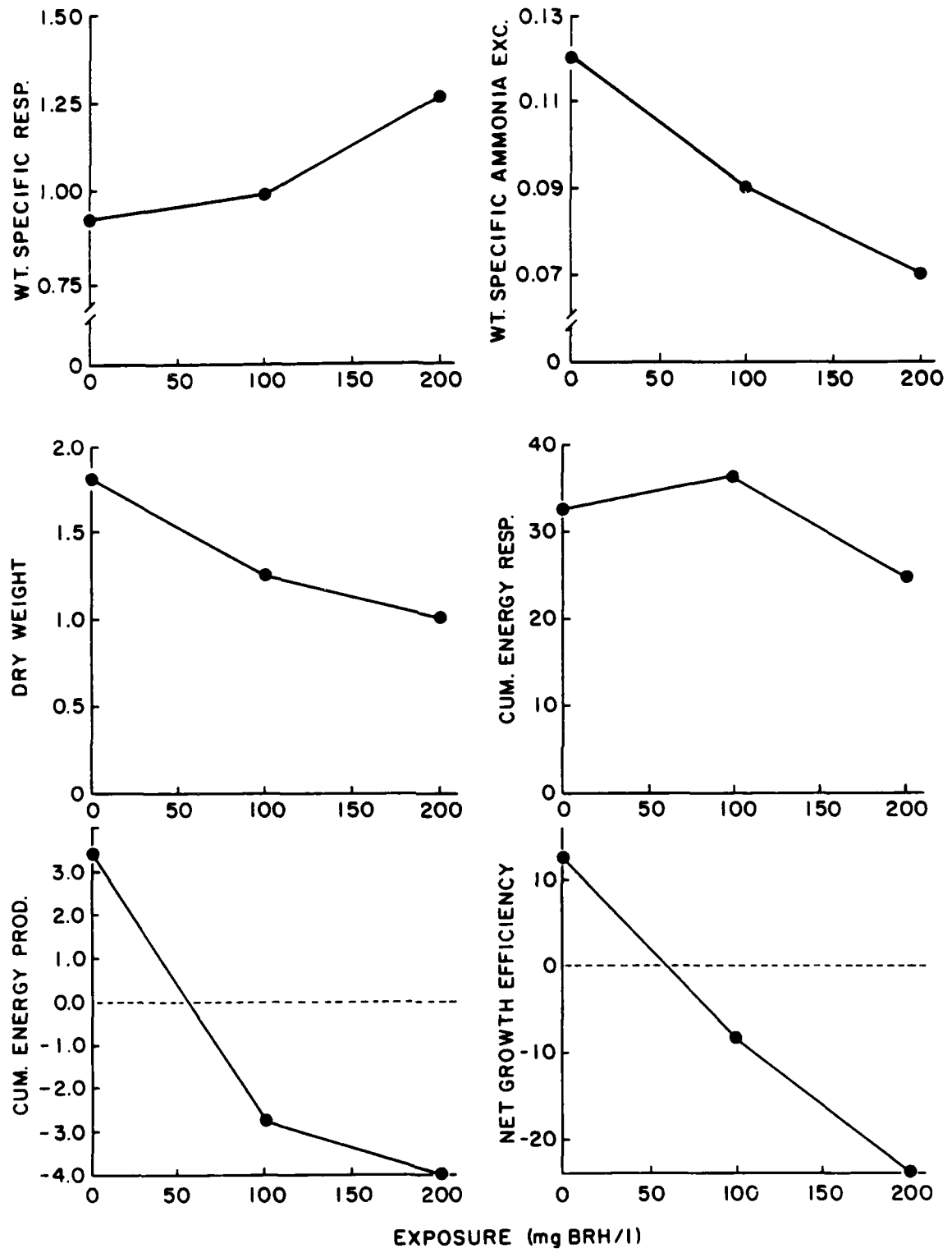


Figure 19. Exposure-response relationships for the bioenergetic endpoints in *N. incisa* exposed to BRH sediment in the laboratory. Weight-specific ammonia excretion (µg NH_4/mg/hr); weight-specific respiration (µl O_2/mg/hr); dry weight (mg); cumulative energy of respiration (joules); cumulative energy production (joules); net growth efficiency (percent)

depth of the core used for determining the contaminant concentrations at 400E was 2 cm. This introduced a potential error range of 4- to 20-fold resulting from dilution with cleaner deeper sediments.

101. The apparent relationship between field conditions and lab exposure is supported by examination of the exposure estimates derived from the tissue residue data for *N. incisa*. Using the PCB tissue residues from the field and the exposure-residue relationship from the laboratory studies, the amount of BRH sediment exposure necessary to produce the field tissue residue can be calculated. Using this approach, the estimated exposures at 400E ranged from 50 to 131 mg/ℓ BRH suspended sediments during the immediate postdisposal period when bioenergetic effects were evident from this station (Tables 23 and 24). These exposures are well within the response range for the bioenergetic endpoints as determined from the laboratory studies.

102. In summary, the results of laboratory/field comparisons of tissue residues based on cluster analysis indicate that there was overlap between both sets of residues and therefore, by inference, the exposure environments for *N. incisa*. There were statistically significant treatment differences between the bioenergetic endpoints measured in the laboratory, which reflected a strong exposure-response relationship. Similarly, statistically significant differences between REFS and 200E and 400E were determined for *N. incisa* exposed in the field. However, it is important to note that the pattern of bioenergetic response measured in the laboratory was different from that in the field. Based upon the laboratory data for the bioenergetic endpoints, an exposure-response threshold was estimated to be 30 to 50 mg/ℓ of BRH sediment. Field exposures for 200E and 400E, calculated from tissue residue-exposure relationships and physical data, ranged from 51 to 131 mg/ℓ during those sampling periods when bioenergetic differences were reported. The predicted exposures to BRH sediment in the field were within the range reported to cause effects in the laboratory although the physiological changes observed in the field were different from those observed in the laboratory portions of this study.

Residue-Effects Relationships

103. Residue-effects relationships were examined in the laboratory for Experiment 4. In this experiment, samples of *N. incisa* were analyzed for tissue residues on days 28 and 42 for 0-, 50-, and 100-percent treatments. In

addition, for the same sampling periods and treatments, each of the bioenergetic responses was quantified. This permitted the comparison of six tissue residues with six bioenergetic measurements for each of the 12 contaminants. The correlation coefficients and probability values resulting from the linear regression analyses are summarized in Table 25.

104. There was a high degree of correlation between 9 of the 12 selected contaminants and the following bioenergetics endpoints: dry weight, cumulative energy for production, and net growth efficiency. When it did occur, the relationship between the bioenergetic response and tissue residue was inverse; that is, as the residue values increase, the magnitude of the bioenergetic response decreased--the exceptions being benzo(a)pyrene, iron, and chromium. Weight-specific respiration was correlated only with cadmium, and the cumulative energy for respiration did not correlate with any of the contaminants. Weight-specific excretion was correlated with the PAHs, except for benzo(a)pyrene and Ethylan, but was not correlated with PCBs or any of the metals.

105. Similar analyses were conducted for the tissue residues and weight-specific respiration and excretion measured in the field (Table 26). These analyses were complicated by seasonal differences in temperature which in turn have an effect on the bioenergetic endpoints as well as the bioaccumulative processes involved in the formation of contaminant tissue residues. To examine this issue, both tissue residues and biological endpoints were compared with temperature using linear regression analysis. Temperatures between 11.6° and 21.3° C were not related to either biological endpoint or tissue residue, which then permitted a direct comparison of tissue residues and effects (Table 26). The results of these analyses demonstrate that, in general, the field bioenergetics responses did not correlate with field tissue residues. The exceptions include the PCBs ($P \leq 0.05$), where the linear model showed a correlation of 0.61 with respiration and 0.71 with excretion. In addition, excretion was significantly ($P \leq 0.05$) correlated with benzo(a)pyrene ($r = -0.61$) and iron ($r = -0.69$), while respiration showed no other significant correlations with tissue residues.

Table 25

Summary of Correlation Analyses of Bioenergetic Effects and Tissue Residues for *N. incisa* Exposed in the Laboratory*

Contaminant	Bioenergetic Effects					
	Dry Weight	Weight-Specific Respiration	Weight-Specific Excretion	Cumulative Energy for Production	Cumulative Energy for Respiration	Net Growth Efficiency
PCB	-0.900**	NS††	NS	-0.865	NS	-0.894
	0.014†			0.014		0.016
SUM PAH	-0.862	NS	-0.831	-0.862	NS	-0.899
	0.027		0.041	0.027		0.015
CENTROID	-0.529	NS	NS	-0.909	NS	-0.881
	0.012			0.012		0.020
Phenanthrene	-0.802	NS	-0.805	-0.802	NS	-0.822
	0.055		0.053	0.055		0.045
178 homologs	-0.904	NS	-0.837	-0.904	NS	-0.949
	0.013		0.038	0.013		0.004
Fluoranthene	-0.925	NS	-0.805	-0.925	NS	-0.966
	0.008		0.053	0.008		0.002
Benzo(a)pyrene	NS	NS	NS	NS	NS	NS
Ethylan	-0.904	NS	-0.865	-0.904	NS	-0.963
	0.013		0.026	0.013		0.002
Iron	NS	NS	NS	NS	NS	NS
Cadmium	-0.846	-0.884	NS	-0.846	NS	-0.921
	0.034	0.019		0.034		0.009
Copper	-0.905	NS	NS	-0.905	NS	-0.963
	0.013			0.013		0.002
Chromium	NS	NS	NS	NS	NS	NS

* N = 6.
** Correlation coefficient.
† Actual probability value for the linear model.
†† Not sampled.

Table 26

Summary of Correlation Analyses of Bioenergetic Effects and Tissue Residues for *N. incisa* Exposed in the Field*

Contaminant	Bioenergetic Effects	
	Weight-Specific Respiration	Weight-Specific Excretion
PCB	-0.609**	-0.706
	0.036†	0.009
SUM PAH	-0.531	-0.531
	0.076	0.074
CENT	-0.557	-0.559
	0.069	0.060
Phenanthrene	-0.452	-0.373
	0.141	0.234
178 homologs	-0.506	-0.482
	0.093	0.112
Fluoranthene	-0.510	-0.414
	0.089	0.180
Benzo(a)pyrene	-0.544	-0.613
	0.067	0.034
Ethylan	--	--
Iron	-0.530	-0.693
	0.094	0.018
Cadmium	-0.083	-0.371
	0.802	0.262
Copper	-0.145	-0.032
	0.670	0.909
Chromium	-0.173	-0.055
	0.610	0.875

* N = 12.
** Correlation coefficient;
† Actual probability value for the linear model.

PART IV: DISCUSSION

Laboratory Studies

106. *Nephtys incisa* is a nonselective deposit feeder typically found in soft sediments. It does not build permanent tubes, but rather burrows indiscriminately, ingesting sediment and associated microorganisms as a food source (Carey 1962, Davis and Miller 1979). This species is considered a member of the equilibrium assemblage in Long Island Sound (Rhoads and Germano 1982) and is usually associated with sediments that are oxygenated to depths of up to 10 cm. The physical effects of the errant burrowing behavior of *N. incisa* on local sediments provide vertical particle mixing and the enhancement of pore water exchange (Rhoads and Germano 1982). Much of the burrowing activity occurs at the redox boundary, a zone typically high in microorganism productivity (Yingst and Rhoads 1980).

107. All of the biological endpoints evaluated with *N. incisa* demonstrated an exposure-response relationship to additions of BRH sediment (Figure 19). Net growth efficiencies for *N. incisa* juveniles maintained in the 0-percent BRH treatments are within the range of efficiencies reported for polychaetes under a variety of conditions. For instance, Carey (1962) estimated population production and respiration values for *N. incisa* from a Long Island Sound study site. Using data from Carey's Table 9, a mean net growth efficiency of 36 percent is calculated (population production/population production + respiration). Net growth efficiency for omnivorous polychaetes (both indiscriminate sediment ingesters and surface detrital feeders) has been found to be generally between 14 and 40 percent (Kay and Brafield 1973, Tenore and Gopalan 1974, Neuhoff 1979).

108. In a previous study, Johns, Gutjahr-Gobell, and Schauer (1985) reported that *N. incisa* juveniles exhibited modifications of bioenergetic responses when exposed to BRH material under laboratory conditions. Changes attributed to exposure to BRH sediment included increased maintenance costs, reduced tissue growth and weight loss, and lowered net growth efficiency. Laboratory data reported in this study confirm and extend these findings.

109. The results of the present study indicate that *N. incisa* living in reference sediment are physiologically affected by exposure to suspended BRH particles. The bioenergetic effects of suspended BRH material were evidenced

in some physiological processes during the first 10 days of exposure, when differences in tissue production and maintenance costs were noted (Table 13). Continued exposure to BRH material did not appreciably alter the types of physiological changes observed in the worms, but rather magnified the physiological effects noted at day 10 (Tables 14 and 15).

110. *Nephtys incisa*, through normal burrowing and irrigation activities, develop an exposure environment within their burrows by actively pumping overlying water and suspended particles from the sediment/water interface into the burrow system. Water entering the burrow system comes into contact with the body and respiratory surfaces of the worm. In addition, suspended particles drawn into the burrow system would tend to settle out of the water onto burrow surfaces, while any waterborne contaminants would tend to become associated with the relatively contaminant-free particles in the borrow walls (Davis 1983). Burrowing, irrigation, and feeding activity would bring the worms into contact with the contaminated particles directly or through association with the burrow walls.

111. Contaminants entering the burrow system are either in a dissolved form or associated with particles. Because of the high suspended sediment levels (200 mg/ℓ) used in these laboratory studies, most of the contaminants are primarily particle associated. Monitoring of the PCB levels in the dosing chambers during the experiments, for example, indicates that approximately 98 percent of the total PCBs present in the water column was associated with the particulate fraction.* Furthermore, Yevich et al. (1986) report that the only histological abnormalities found in *N. incisa* exposed to BRH material in the laboratory experiments are thickening of the epidermis and the appearance of macrophages containing black particles. They concluded that the changes in epidermal structure were due to direct contact with BRH particles.

112. The overall effect of exposure to BRH material is to impact the way in which assimilated energy is partitioned between growth functions and maintenance costs. Worms from treatments containing 100 mg/ℓ suspended BRH material exhibited significant reductions in net growth efficiency following a 10-day exposure. As exposure concentrations and duration increase, a greater proportion of assimilated energy is required for general physiological

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* Personal Communication, Peter Rogerson, 1986, US Geological Survey, Denver, Colo.

maintenance. This results in less energy being available for conversion to new tissue. In fact, in those treatments containing increasing amounts of BRH material, there is a net loss in tissue (dry weight) during the exposure period, indicating that tissue is being catabolized to meet some of the increase in maintenance costs.

113. Exposure to suspended BRH material affected two key physiological functions. First, maintenance costs increased as both the concentration and duration of BRH exposure increased. Following 10 days of exposure, juvenile worms from treatments containing >50 percent BRH sediment (100 mg/ℓ) in the suspended load exhibit significantly increased maintenance costs. This pattern persisted during the exposure period for all experiments except the 42-day sampling time of Experiment 4. AT 42 days, no significant differences were apparent between 0- and 50-percent BRH treatments. Juveniles from the 100-percent BRH treatment, however, did exhibit increased maintenance costs.

114. The second physiological effect noted with *N. incisa* juveniles exposed to suspended BRH sediment was a decrease in growth during the experimental period. Reductions in growth were not consistently apparent until 28 days of exposure. By 42 days exposure, growth in worms from the three treatments could be statistically separated, with individuals from the 100-percent BRH treatment (200 mg/ℓ) having the lowest value (net loss of 28 percent) and worms from the 0-percent BRH treatment having the highest (net gain of 20 percent).

115. For periods shorter than 28 days, effects on growth were equivocal. Reductions in growth were noted in one 10-day experiment (Experiment 2) at the 75- and 100-percent BRH treatments. In the other 10-day experiment and the 14-day sampling time of the 28-day experiment, no significant differences were noted in growth of worms from the various treatments. This is in contrast to previous work reported by Johns and Gutjahr-Gobell (1985) in which juvenile *N. incisa* exhibited reductions in growth after 10 days of exposure to BRH material. In these experiments, exposure was provided by either bedded material or settled particles, indicating that direct exposure to contaminated particles is needed to affect growth rates in less than 10 days.

116. Results of the laboratory experiments indicated that there is both an exposure-dependent and time-dependent response to suspended BRH material. Bioenergetic effects of suspended BRH material are evidenced in some physiological processes during the first 10 days of exposure when differences in

tissue production and maintenance costs were noted. Continued exposure to BRH material does not appreciably alter the types of physiological changes observed in the worms but rather magnifies the physiological effects noted by day 10. The overall effect of exposure to BRH material is to impact the way in which assimilated energy is partitioned between growth functions and maintenance costs. Since the BRH material was introduced and maintained as part of the suspended load, it appears the exposure was primarily through active irrigation of the burrow tube and ingestion of settled particles.

Field Studies

117. There are two clear patterns in the physiological data from the field studies. First, juvenile worms exhibit seasonal changes in physiological functions. Second, sampling station-specific differences in physiological parameters were also noted, during particular periods of the year.

118. Seasonal changes in respiration and ammonia excretion rate were found in *N. incisa* juveniles collected at all FVP stations. These changes follow a pattern similar to the seasonal changes in bottom water temperature recorded during field sample collections (Table 1). Aerobic respiration and ammonia excretion rates were greatest at those collection times when bottom water temperatures were highest. Conversely, the lowest physiological rates were found at times when the water temperature was lower.

119. The rate patterns for physiological functions noted in this study are consistent with seasonal changes in the physiology and biochemistry of *N. incisa* juveniles collected from an area adjacent to the REFS sampling site between October 1982 and September 1983 (Johns and Gutjahr-Gobell 1987). In this study, worms were found to exhibit seasonally dependent rate functions for respiration, growth, and the accumulation of lipid reserves. Carey (1962) also reported seasonal changes in respiration and growth rates of *N. incisa* collected from Long Island Sound.

120. Although a temporal pattern for physiological functions was noted at all stations, significant spatial differences in respiration and ammonia excretion rates did occur at certain times of the year. Significant differences in both respiration rate and ammonia excretion rate were found when bottom water temperatures exceeded 11° C. When temperatures were below 11° C, no significant differences were noted between the stations. This pattern was

apparent for the 3 years in which field sampling was conducted.

121. Depending upon the time of the year, water temperature appears to alter the apparent effects of exposure to BRH material on the physiological functions of *N. incisa*. Upon comparison of the temperatures in Table 1 and the physiological responses in Tables 23 and 24, it is seen that when the ambient temperature was above 11° C, statistically significant differences were found between stations at times T + 2, T + 8, T + 12, T + 16, T + 74, and T + 117. This is not surprising considering the role that temperature plays in controlling physiological and biochemical processes in poikilotherms. As noted earlier, *N. incisa* are physiologically more active during periods of warm water temperature, exhibiting their highest rates for growth, maintenance costs, and lipid accumulation (Johns and Gutjahr-Gobell 1987) and their greatest burrowing activity (Davis and Miller 1979). As the polychaete becomes more active, the effective exposure to contaminants should also increase. Increased activity will cause an increase in tube irrigation frequency which, in turn, brings about a greater exchange of water between the burrow and overlying waters. Particles containing contaminants found in the suspended load would be expected to enter the burrow system more frequently during times of increased irrigation activity; this may have depressed the physiological responses.

Laboratory-to-Field Comparisons

122. A primary objective of this program is to field verify the laboratory biological responses by measuring the same response under both laboratory and field exposures. A basic and often implicit assumption is that results derived from laboratory tests are directly applicable in the field. The hypothesis, explicitly stated, is that there are no significant differences in the exposure-response relationships measured for the same species in both the laboratory and the field. the acceptance of this hypothesis is necessary in order to extrapolate laboratory data to the field. However, as previously stated, a rigorous statistical test of this hypothesis requires defining field exposure at a level of resolution comparable to that in the laboratory. Because our field exposure data are discrete rather than continuous, the comparison between laboratory and field responses will of necessity be limited to comparing exposure boundaries rather than absolutes.

123. Exposure conditions must be examined to determine whether the organism responses are based on comparable situations in the laboratory and the field. Physical data were used to make three estimates of exposure to BRH material at the FVP stations. Water chemistry data were used to estimate milligrams BRH/ℓ 1 m above the bottom at the FVP stations (Nelson et al. 1987). With the assumption of a 10× enrichment from the value at 1 m above the bottom, there is a predicted exposure at the sediment/water interface of 6 to 13 mg BRH/ℓ at the FVP stations as a result of disposal at the FVP site. Estimates of exposure via resuspension of surficial sediment predict much higher concentrations. A worst-case estimate assumes that all of the predicted suspended solids are BRH material from the disposal mound. This estimate predicts up to 100 mg BRH/ℓ under quiescent conditions and up to 300 mg BRH/ℓ under storm conditions. A more probable estimate assumes that sediments resuspended at each station are the source of contaminants for the suspended solids. This estimate predicts a graded exposure at the FVP stations with maximum values of 40 mg/ℓ at 200E, 12 mg/ℓ at 400E, and 4 mg/ℓ at 1000E for quiescent conditions. These values increase to 120 mg/ℓ at 200E, 40 mg/ℓ at 400E, and 10 mg/ℓ at 1000E for storm conditions.

124. If it is assumed that tissue concentrations in *N. incisa* are directly related to exposure concentrations, this relationship may be used to test the reasonableness of the exposure predictions. This assumption is reasonable, based on results from laboratory experiments. A cluster analysis of all *N. incisa* tissue residue data revealed no consistent clustering of the laboratory data separate from the field data. Any apparent clusters included both laboratory and field data. Therefore, if it is assumed that tissue concentrations reflect exposure concentrations, this association of laboratory and field tissue concentration data indicates an overlap of laboratory exposure conditions with field exposure conditions. The maximum estimates of field exposures to BRH sediment (milligrams per litre) suspended at the sediment/water interface based on PCB tissue residues in field-collected *N. incisa* are up to 12 mg/ℓ at REFS, 88 mg/ℓ at 1000E, and 130 mg/ℓ at 400E (Table 20).

125. Assuming that exposures were due to initial dispersion of BRH sediments during disposal and subsequent resuspension and movement of sediments from the dredged material mound, a combination of estimates seems appropriate. The estimate based on water chemistry predicts exposures of at least 6 mg/ℓ at

the sediment/water interface at all FVP stations during disposal activities in CLIS. The worst-case resuspension estimate predicts exposures of up to 100 mg/ℓ in the vicinity of the disposal mound. These estimates (6 to 100 mg/ℓ agree well with those predicted by the tissue concentration exposure concentration relationship (12 to 130 mg/ℓ). The laboratory exposures for the bioenergetic responses were 0 and 200 mg BRH/ℓ as suspended solids. These laboratory exposures overlap the estimated range of exposures observed in the field for clean control conditions at REFS, and worst-case storm conditions near the disposal mound.

126. More specific comparisons can be made between respiration and ammonia excretion data collected in the laboratory and similar types of data collected for worms from the FVP stations at T + 2 (14 days) and T + 8 (56 days). These two field sampling periods are ones in which the temporal scale of the laboratory studies is matched with the field exposures. Statistically significant differences were observed in weight-specific respiration and ammonia excretion rates of juvenile worms collected from the various stations at T + 2 and T + 8, with worms from the stations closest to the center of the disposal mound (200E and 400E) exhibiting the lowest rates.

127. Significant differences in respiration rate were also noted in worms maintained in treatments containing >100 mg/ℓ BRH suspended sediment. The main difference between the laboratory and field data is that the field data indicate significant decreases in respiration rate (relative to worms from the REFS station) relative to sampling stations associated with increased BRH sediment, while the laboratory treatment resulted in significant increases in respiration rates with increasing concentrations of BRH material. Although the apparent shift in respiration rates between field and laboratory exposures is perplexing, one possible explanation for the differences in response is the probable differences in exposure environment between the two phases of this study.

128. The primary exposure route in the current laboratory studies was through contact with suspended particles pumped into the burrow system and across body surfaces. In the field, worms are also exposed to suspended BRH sediment, as is suggested by the body burden data of specimens from the 1000E station. At the 200E and 400E stations, however, BRH sediment was also present as a bedded sediment surface layer (Germano and Rhoads 1984). At these two sites the exposure environment consisted of both suspended particles

(associated with the nepheloid layer), as well as direct contact with bedded sediment during burrowing.

129. In a previous study on the effects of bedded BRH sediment on the bioenergetics of *N. incisa* juveniles, Johns, Gutjahr-Gobell, and Schauer (1985) found a reduction in growth and net growth efficiency related to increasing percentages of contaminated sediment. The overall result of exposure to bedded sediment was similar to that reported here (negative growth rates, lowered net growth efficiency); however, the underlying reasons for the similar outcomes are different. In the earlier study, worms in bedded BRH sediment exhibited reduced respiration, ammonia excretion, and burrowing activity as compared with worms placed in bedded BRH reference sediment. The decrease in burrowing activity indicated that the worms were probably curtailing physiological functions including feeding. Since the primary energy source of this species is organic carbon associated with ingested sediment, reduced burrowing activity has the effect of starving the individual. Despite the lowered maintenance costs exhibited by individuals in bedded BRH sediment, Johns, Gutjahr-Gobell, and Schauer (1985) found that worms in bedded BRH sediment lost weight during the experimental period. This suggests that the worms may have catabolized tissue to meet the energy requirements for routine activity and sediment ingestion. A similar effect might well have occurred at the stations where bedded BRH sediment was found (200E and 400E).

130. Although it is difficult to interpret the significance of oxygen consumption and ammonia excretion data when presented alone (as was the case for the field data), the fact that controlled laboratory studies (Johns, Gutjahr-Gobell, and Schauer 1985) were also conducted with the same material under similar types of exposure environments does permit some conclusions to be drawn from the field data. It is evident from the laboratory studies that exposure to bedded BRH material does have a a negative impact on growth rates. Reductions in growth rate could also be expected to occur in worms from the 200E and 400E sampling stations when bedded sediment is likely to occur.

131. Reductions in growth are only expected in the warmer months when burrowing activity is expected to increase and growth rates should be the greatest. Seasonal patterns in physiological rate functions were found at all FVP stations and were noted by Johns and Gutjahr-Gobell (1987). Despite the seasonal increases in maintenance costs that usually occur with warmer temperatures, Johns and Gutjahr-Gobell reported that net growth efficiency remains

fairly constant throughout the year. the consequences of reductions in consuming sufficient energy, especially in the summer months, would be to reduce the amount of energy available for growth. Although growth was not directly measured during the field phase of this study, data from field-collected specimens, coupled with data from laboratory studies in the 1985 report, would predict significant reductions in growth rate of *N. incisa* juveniles from the 200E and 400E sampling stations. An examination of *N. incisa* population dynamics which is currently being conducted at the FVP site (Zajac and Whitlatch 1985) will further define the overall effects of exposure to BRH sediment on the growth rate of juveniles from the various sampling stations.

Residue-Effects Relationships

132. There was a strong link between exposure to BRH sediment and subsequent tissue residues in *N. incisa*, as confirmed by the laboratory data collected during Experiment 4. The relationship between worm tissue residues tracked the BRH exposure concentrations remarkable well. For example, PCBs, Ethylan, fluoranthene, SUM of PAHs, and SUM of alkyl homologs all exhibit a near-linear relationship with exposure concentrations.

133. The net growth efficiency data for *N. incisa* exposed in the laboratory illustrate the relationship between exposure to BRH material and physiological dysfunction. Since there is a positive correlation between BRH sediment concentration and contaminant tissue residues, it follows that observed physiological effects also correlate with those contaminants forming tissue residues. It is important to note, however, that such correlations are not to be interpreted as implying cause and effect.

PART V: CONCLUSIONS

134. There were three primary objectives in the FVP. The first objective was to test the applicability of biological energetic techniques to measure physiological effects of exposure to contaminated dredged material, and to determine the degree of variability and reproducibility inherent in the procedure. The second objective was to field verify the response observed in the laboratory and to determine the accuracy of the laboratory prediction. The third objective was to determine the degree of correlation between contaminant tissue residues accumulated from dredged material and the bioenergetic responses observed in both the laboratory and the field.

135. Bioenergetic techniques were applied to *Nephtys incisa*, an infaunal polychaete dominant in the benthic community at the Central Long Island Sound disposal site. Four laboratory experiments were conducted with *N. incisa*; these experiments indicated a strong exposure-response relationship to BRH suspended sediments.

136. Two physiological responses were noted in the field studies. First, juvenile worms exhibited seasonal change in physiological functions that are correlated with changes in bottom water temperatures. Second, significant differences between the FVP stations were found during these sampling periods when water temperatures were above 11.6° C. Water temperature appears to alter the apparent effects of exposure to BRH material on the physiological functions of *N. incisa*. The increased impact of BRH material at warmer temperatures may be due to increases in physiological and behavioral activity that generally accompany increasing temperatures.

137. Comparisons of laboratory and field data for respiration and ammonia excretion rates indicated that BRH had an impact in both exposure environments, although the direction of the change in the response of the bioenergetic parameters was different. The responses of bioenergetics parameters for worms collected in the field were similar to previous laboratory results with *N. incisa* using bedded sediments as the exposure environment rather than suspended sediments. FVP stations 200E and 400E both contain a layer of settled BRH material. It was at these two stations that significant reductions in respiration and ammonia excretion rates, similar to laboratory results with bedded sediments, were noted. Overall data from the laboratory and field studies indicated that the exposure environment for an infaunal species

includes contact with bedded material around the mound and suspended particles off the mound and offsite.

138. Correlations were found in the laboratory between the tissue residues of several chemicals and growth, cumulative energy for production, and net growth efficiency, but not between tissue residues and weight-specific respiration and excretion in the laboratory. Weight-specific respiration and excretion measured in the field was generally unrelated to tissue residues, as would have been predicted from the laboratory data. PCBs and selected PAHs, however, did show a relationship to weight-specific respiration and ammonia excretion rate.

139. The bioenergetics endpoints measured in this study demonstrated the sensitivity of these responses to dredged material. The responses and associated variances are predictable under controlled conditions permitting statistical treatment of data. To be of maximum value in predicting potential effects from dredged material disposal, the complete suite of bioenergetics responses must be measured since respiration and excretion measurements by themselves have little interpretive value. Of all the bioenergetics variables evaluated in this study, growth, cumulative energy for production, and net growth efficiency (although they could not be evaluated in the field) were, in the laboratory, the most sensitive and of the greatest interpretative value.

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APPENDIX A: CHEMICAL FORMULAS AND FIELD WORM RESIDUE CONCENTRATIONS

Table A1

Chemical Contaminants Selected for Measurement

in Both Field and Laboratory Studies

Chlorinated hydrocarbon pesticides

Polychlorinated biphenyls
Ethylan

Aromatic hydrocarbons ≥ molecular weight 166:

Compound Class	Molecular Weight
Fluorene	166
C-1* Fluorene	180
C-2* Fluorene	194
C-3* Fluorene	208
C-4* Fluorene	222
Phenanthrene	178
Anthracene	178
C-1* Phenanthrene/anthracene	192
C-2* Phenanthrene/anthracene	206
C-3* Phenanthrene/anthracene	220
C-4* Phenanthrene/anthracene	234
Fluoranthene	202
Pyrene	202
C-1* Fluoranthene/pyrene	216
C-2* Fluoranthene/pyrene	230
C-3* Fluoranthene/pyrene	244
C-4* Fluoranthene/pyrene	258
Benzanthracene/chrysene**	228
C-1* Benzanthracene/chrysene**	242
C-2* Benzanthracene/chrysene**	256
C-3* Benzanthracene/chrysene**	270
C-4* Benzanthracene/chrysene**	284

(Continued)

* C-1, C-2, C-3, and C-4 refer to the number of methyl groups substituted somewhere in the parent compound.

** These names are representative of the class of polynuclear aromatic hydrocarbons (PAHs) measured at each molecular weight.

Table A1 (Concluded)

Compound Class	Molecular Weight
Benzofluoranthenes	252
Benzo(e)pyrene	252
Benzo(a)pyrene	252
Perylene	252
C-1* Benzopyrene/perylene**	266
C-2* Benzopyrene/perylene**	280
C-3* Benzopyrene/perylene**	294
C-4* Benzopyrene/perylene**	308
Benzoperylene**	276
Dibenzanthracene**	278
Coronene	300
Dibenzocrysene**	302
Hetrocyclic aromatic compounds	
Dibenzothiopehen	184
C-1* Dibenzothiophene	198
C-2* Dibenzothiophene	212
C-3* Dibenzothiophene	226
C-4* Dibenzothiophene	240
Metals	
Cadmium	
Copper	
Chromium	
Iron	
Lead	
Manganese	
Nickel	
Zinc	

* C-1, C-2, C-3, and C-4 refer to the number of methyl groups substituted somewhere in the parent compound.

** These names are representative of the class of polynuclear aromatic hydrocarbons (PAHs) measured at each molecular weight.

Table A2

Complete Formulae for Calculating all SUM and CENT Variables

PSUM = POS166 + POS178 + POS202 + POS228 + POS252 + POS276 + POS278 + POS300 + POS302

HSUM = H1C166 + H2C166 + H3C166 + H4C166 + H1C178 + H2C178 + H3C178 + H4C178 + H1C202 + H2C202 + H3C202 + H4C202 + H1C228 + H2C228 + H3C228 + H4C228 + H1C252 + H2C252 + H3C252 + H4C252

SUM = POS166 + H1C166 + H2C166 + H3C166 + H4C166 + POS178 + H1C178 + H2C178 + H3C178 + H4C178 + POS202 + H1C202 + H2C202 + H3C202 + H4C202 + POS228 + H1C228 + H2C228 + H3C228 + H4C228 + POS252 + H1C252 + H2C252 + H3C252 + H4C252 + POS276 + POS278 + POS300 + POS302

PCENT = [POS166*166 + POS178*178 + POS202*202 + POS228*228 + POS252*252 + POS276*276 + POS278*278 + POS300*300 + POS302*302]/PSUM

HCENT = [H1C166*180 + H2C166*194 + H3C166*208 + H4C166*222 + H1C178*192 + H2C178*206 + H3C178*220 + H4C178*234 + H1C202*216 + H2C202*230 + H3C202*244 + H4C202*258 + H1C228*242 + H2C228*256 + H3C228*270 + H4C228*284 + H1C252*266 + H2C252*280 + H3C252*294 + H4C252*308]/HSUM

CENT = [POS166*166 + H1C166*180 + H2C166*194 + H3C166*208 + H4C166*222 + POS178*178 + H1C178*192 + H2C178*206 + H3C178*220 + H4C178*234 + POS202*202 + H1C202*216 + H2C202*230 + H3C202*244 + H4C202*258 + POS228*228 + H1C228*242 + H2C228*256 + H3C228*270 + H4C228*284 + POS252*252 + H1C252*266 + H2C252*280 + H3C252*294 + H4C252*308 + POS276*276 + POS278*278 + POS300*300 + POS302*302]/SUM

The sum of alkyl homologs of PAH molecular weight 178 (HOS178) is calculated according to the following formula:

HOS178 = H1C178 + H2C178 + H3C178 + H4C178

where

HOS178 = sum of C-1 to C-4 alkyl-substituted 178 PAHs

This statistic was chosen to describe the alkyl homologs because the 178 alkyl homologs are the most intense homologs within the Black Rock Harbor (BRH) PAH distribution and because they afford the greatest BRH to REFS concentration ratio. Alkyl homologs were included because of potential differences between them and parent PAHs.

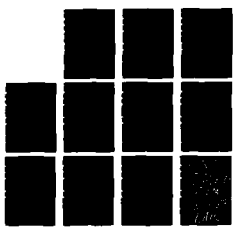
Table A3

Tissue Residue Concentrations in *N. incisa* from the T - 39 Weeks Field Collection in CLIS (17 Aug 82)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	189	--	210
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

AD-A194 228 FIELD VERIFICATION PROGRAM (AQUATIC DISPOAL) 2/2
BIOENERGETIC EFFECTS OF BLA (U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR
UNCLASSIFIED D M JOHNS ET AL MAR 88 WES/TR/D-88-3 F/G 8/1 NL



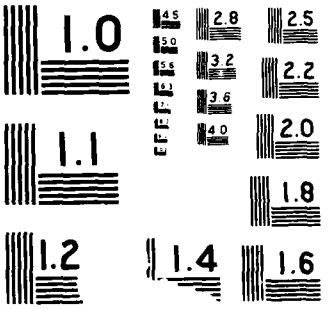

1.0
1.1
1.2
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0

Table A4

Tissue Residue Concentrations in *N. incisa* from the T - 26 Weeks Field Collection in CLIS (16 Oct 82)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of i78 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	240	--	290
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A5

Tissue Residue Concentrations in *N. incisa* from the T - 13 Weeks Field Collection in CLIS (16 Feb 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	5.6	--	4.0
Sum of 178 alkyl homologs	--	67	--	34
Fluoranthene	--	37	--	26
Benzo(a)pyrene	--	19	--	10
Ethylan	--	0	--	0
PCB as A1254	--	340	--	290
SUM of PAHs	--	780	--	530
Centroid of PAHs	--	242.9	--	244.4
Copper	--	18.1	--	21
Cadmium	--	0.1	--	0.5
Chromium	--	1.3	--	1.9
Iron	--	570	--	770

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A6

Tissue Residue Concentrations in *N. incisa* from the T - 11 Weeks Field Collection in CLIS (04 Mar 83)*

Chemical Compound	Station				
	CNTR	200E	400E	1000E	REFS
Phenanthrene	--	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--	--
Fluoranthene	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--
Ethylan	--	--	--	--	--
PCB as A1254	--	--	--	--	--
SUM of PAHs	--	--	--	--	--
Centroid of PAHs	--	--	--	--	--
Copper	36	39	37	42	26
Cadmium	0.8	0.5	0.7	1.0	0.6
Chromium	2.9	1.7	1.7	2.4	2.0
Iron	980	790	760	980	1,040

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A7

Tissue Residue Concentrations in *N. incisa* from the T - 5 Weeks Field Collection in CLIS (12 Apr 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	10.7	--	9.6
Sum of 178 alkyl homologs	0	79	0	50
Fluoranthene	--	47	--	35
Benzo(a)pyrene	--	24	--	21
Ethylan	--	0	--	0
PCB as A1254	--	390	--	340
SUM of PAHs	--	960	--	710
Centroid of PAHs	--	241.4	--	243.7
Copper	--	49	--	28
Cadmium	--	0.5	--	0.6
Chromium	--	3.9	--	2.1
Iron	--	1,360	--	930

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A8

Tissue Residue Concentrations in *N. incisa* from the T + 2 Weeks Field Collection in CLIS (02 Jun 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	360	60	6.2
Sum of 178 alkyl homologs	--	3,690	840	44
Fluoranthene	--	970	197	19
Benzo(a)pyrene	--	250	85	13
Ethylan	--	0	0	0
PCB as A1254	--	1,060	630	290
SUM of PAHs	--	15,100	4,200	420
Centroid of PAHs	--	221.9	229.3	241.0
Copper	--	37	23	--
Cadmium	--	0.6	0.2	--
Chromium	--	1.1	1.2	--
Iron	--	670	680	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A9

Tissue Residue Concentrations in *N. incisa* from the T + 7 Weeks Field Collection in CLIS (03 Jul 83)*

Chemical Compound	Station CNTR	400E	1000E	REFS
Phenanthrene	--	300	8.3	7.8
Sum of 178 alkyl homologs	--	3,700	260	79
Fluoranthene	--	650	49	31
Benzo(a)pyrene	--	420	66	19
Ethylan	--	0	0	0
PCB as A1254	--	1,160	630	290
SUM of PAHs	--	16,700	1,980	840
Centroid of PAHs	--	229.5	241.4	243.3
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A10

Tissue Residue Concentrations in *N. incisa* from the T + 8 Weeks Field Collection in CLIS (13 Jul 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	--	27	37	--
Cadmium	--	0.3	0.5	--
Chromium	--	3.2	1.9	--
Iron	--	520	690	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A11

Tissue Residue Concentrations in *N. incisa* from the T + 16 Weeks Field Collection in CLIS (06 Sep 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	14.3	9.8	7.3
Sum of 178 alkyl homologs	--	890	420	66
Fluoranthene	--	165	111	37
Benzo(a)pyrene	--	195	85	27
Ethylan	--	0	0	0
PCB as A1254	--	1,240	1,000	370
SUM of PAHs	--	5,900	2,900	850
Centroid of PAHs	--	239.0	239.4	243.8
Copper	--	27	37	26
Cadmium	--	0.2	0.4	0.5
Chromium	--	1.8	2.3	2.2
Iron	--	650	970	1,210

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A12

Tissue Residue Concentrations in *N. incisa* from the T + 28 Weeks Field Collection in CLIS (29 Nov 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	48	5.8	3.4
Sum of 178 alkyl homologs	--	870	93	34
Fluoranthene	--	210	36	23
Benzo(a)pyrene	--	122	35	16
Ethylan	--	0	0	0
PCB as A1254	--	690	480	240
SUM of PAHs	--	5,100	1,330	550
Centroid of PAHs	--	232.7	249.4	248.4
Copper	--	40.0	17.8	--
Cadmium	--	0.4	0.2	--
Chromium	--	1.8	1.4	--
Iron	--	790	530	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A13

Tissue Residue Concentrations in *N. incisa* from the T + 44 Weeks Field Collection in CLIS (20 Mar 84)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	220	4.4	4.6	1.5
Sum of 178 alkyl homologs	1,100	950	18	1.2
Fluoranthene	270	230	31	24
Benzo(a)pyrene	159	132	22	10
Ethylan	0	0	0	0
PCB as A1254	650	580	350	220
SUM of PAHs	4,900	4,300	380	183
Centroid of PAHs	221.2	224.7	235.0	233.1
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A14

Tissue Residue Concentrations in *N. incisa* from the T + 56 Weeks Field Collection in CLIS (13 Jun 84)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	174	--	44	39
Cadmium	1.0	--	0.6	0.7
Chromium	5.9	--	2.1	1.9
Iron	380	--	680	770

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A15

Tissue Residue Concentrations in *N. incisa* from the T + 73 Weeks Field Collection in CLIS (10 Oct 84)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	50	44	47	28
Cadmium	1.6	1.2	2.3	1.3
Chromium	3.3	1.0	1.6	1.6
Iron	790	840	930	610

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A16

Tissue Residue Concentrations in *N. incisa* from the T + 74 Weeks Field Collection in CLIS (16 Oct 84)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	500	7.9	5.1	3.2
Sum of 178 alkyl homologs	4,800	200	124	33
Fluoranthene	1,410	96	57	27
Benzo(a)pyrene	102	40	46	19
Ethylan	13.6	0	0	0
PCB as A1254	710	510	350	300
SUM of PAHs	16,000	1,660	1,320	580
Centroid of PAHs	208.1	233.9	242.5	246.3
Copper	86	--	--	--
Cadmium	0.6	--	--	--
Chromium	2.5	--	--	--
Iron	680	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A17

Tissue Residue Concentrations in *N. incisa* from the T + 140 Weeks Field Collection in CLIS (24 Jan 86)*

Chemical Compound	Station				
	CNTR	200E	400E	1000E	REFS
Phenanthrene	7.3	--	4.7	12.0	--
Sum of 178 alkyl homologs	1,070	--	58	390	--
Fluoranthene	300	--	23	78	27
Benzo(a)pyrene	162	--	21	91	23
Ethylan	6.2	--	0	0	0
PCB as A1254	900	--	310	300	160
SUM of PAHs	6,400	--	630	3,000	660
Centroid of PAHs	232.1	--	244.0	244.5	253.7
Copper	83	53	44	46	32
Cadmium	1.8	0.9	0.6	0.8	0.7
Chromium	9.9	4.3	2.4	2.0	2.1
Iron	840	970	1,250	920	970

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

APPENDIX B: CHEMICAL ANALYSIS OF SURFICIAL SEDIMENTS

Table B1

Percentage of Black Rock Harbor (BRH) Sediment in the Surficial Sediments (0-2 cm) and the Contaminants Used for the Percent Calculations

Date	Station			
	CNTR	200E	400E	1000E
	Percentage of BRH Sediment			
Jun 83	44.5	41.1	12.5	1.8
Jul 83	15.0	37.4	3.3	1.6
Sep 83	32.0	36.7	4.9	2.0
Dec 83	32.8	36.1	9.5	4.4
Mar 84	4.4	2.2	1.9	1.8
Jun 84	9.5	15.6	0.5	0.7
Sep 84	10.0	0.8	3.5	0.5
Oct 84	2.6	--	0.2	1.6
Dec 84	35.1	11.3	0.0	1.0
Oct 85	0.2	21.0	0.0	0.0

(Continued)

Table B1 (Concluded)

Date	Station			
	CNTR	200E	400E	1000E
	Contaminants Used			
Jun 83	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	Cd+Cu+Cr
Jul 83	PAH+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Sep 83	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Dec 83	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr
Mar 84	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cu+Cr
Jun 84	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr	Cu+Cr
Sep 84	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cu+Cr	PAH+PCB+Cu+Cr
Oct 84	PAH+PCB	--	PAH+PCB	PAH+PCB
Dec 84	Cd+Cu+Cr	Cd+Cu+Cr	Cu+Cr	Cu+Cr
Oct 85	PCB	PAH+PCB	PCB	PAH+PCB

Table B2

Phenanthrene Concentrations (ng/g Dry Weight) in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	114
12/8/82	--	--	--	--	77
3/2/83	105	101	132	--	107
3/2/83	--	--	--	--	98
3/2/83	--	--	--	--	62
6/3/83	1,560	1,960	910	52	88
6/3/83	--	--	--	63	--
7/26/83	770	1,710	240	174	51
9/1/83	780	1,010	220	168	94
9/1/83	--	--	--	--	81
3/19/84	77	98	100	250	42
3/20/84	--	--	141	78	90
3/20/84	--	--	--	--	76
3/20/84	200	--	--	--	--
9/11/84	147	57	116	109	40
10/16/84	230	--	85	137	123
10/22/85	43	440	38	69	51

Table B3

178 Alkyl Homolog Concentrations (ng/g Dry Weight) in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	210
12/8/82	--	--	--	--	172
3/2/83	250	210	260	--	188
3/2/83	--	--	--	--	230
3/2/83	--	--	--	--	127
6/3/83	--	--	5,300	230	189
6/3/83	--	--	--	122	--
7/26/83	9,700	--	1,500	412	131
9/1/83	5,200	*	1,480	613	186
9/1/83	--	--	--	--	189
3/19/84	1,330	590	560	600	103
3/20/84	--	--	590	260	170
3/20/84	--	--	--	--	185
3/20/84	1,200	--	--	--	--
9/11/84	3,000	270	640	250	103
10/16/84	1,260	--	240	420	240
10/22/85	490	3,800	430	210	192

Table B4

Fluoranthene Concentrations (ng/g Dry Weight) in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	280
12/8/82	--	--	--	--	200
3/2/83	300	260	340	--	270
3/2/83	--	--	--	--	230
3/2/83	--	--	--	--	148
6/3/83	2,300	2,300	1,240	142	220
6/3/83	--	--	--	161	--
7/26/83	1,940	2,600	570	400	140
9/1/83	1,370	2,800	560	380	220
9/1/83	--	--	--	--	210
3/19/84	290	330	330	600	124
3/20/84	--	--	360	210	230
3/20/84	--	--	--	--	185
3/20/84	510	--	--	--	--
9/11/84	650	166	410	250	108
10/16/84	580	--	240	320	300
10/22/85	172	1,770	142	196	189

Table B5

Benzo(a)pyrene Concentrations (ng/g Dry Weight) in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	280
12/8/82	--	--	--	--	220
3/2/83	260	270	310	--	220
3/2/83	--	--	--	--	210
3/2/83	--	--	--	--	173
6/3/83	1,640	1,490	810	122	210
6/3/83	--	--	--	158	--
7/26/83	1,520	1,750	380	370	169
9/1/83	1,000	2,100	570	320	200
9/1/83	--	--	--	--	230
3/19/84	220	350	260	450	155
3/20/84	--	--	400	280	240
3/20/84	--	--	--	--	185
3/20/84	460	--	--	--	--
9/11/84	600	230	400	260	111
10/16/84	450	--	240	320	290
10/22/85	280	1,130	230	196	380

Table B6

SUM PAH Concentrations (ng/g Dry Weight) in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	5,200
12/8/82	--	--	--	--	4,500
3/2/83	5,100	4,900	5,900	--	4,400
3/2/83	--	--	--	--	4,300
3/2/83	--	--	--	--	3,300
6/3/83	62,000	59,000	30,000	2,400	3,900
6/3/83	--	--	--	3,000	--
7/26/83	54,000	63,000	10,100	7,200	3,200
9/1/83	33,000	71,000	13,500	7,200	3,600
9/1/83	--	--	--	--	4,300
3/19/84	7,200	7,100	6,200	9,300	2,700
3/20/84	--	--	7,300	4,500	3,600
3/20/84	--	--	--	--	4,300
3/20/84	11,100	--	--	--	--
9/11/84	18,600	4,400	8,600	5,000	2,000
10/16/84	11,500	--	4,800	6,700	5,800
10/22/85	5,400	34,000	4,900	3,800	5,400

Table B7

Centroid Statistic in Surficial Sediments

Date	Station CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	249.7
12/8/82	--	--	--	--	252.0
3/2/83	247.6	248.9	247.7	--	247.4
3/2/83	--	--	--	--	248.0
3/2/83	--	--	--	--	252.1
6/3/83	238.7	234.1	235.2	241.4	248.3
6/3/83	--	--	--	250.3	--
7/26/83	234.7	232.6	234.4	247.3	252.5
9/1/83	239.7	238.6	244.7	244.3	245.4
9/1/83	--	--	--	--	250.3
3/19/84	237.0	245.1	241.1	244.5	251.0
3/20/84	--	--	243.5	245.3	243.7
3/20/84	--	--	--	--	251.5
3/20/84	242.9	--	--	--	--
9/11/84	240.8	249.2	244.1	247.5	247.2
10/16/84	240.4	--	248.4	247.7	250.0
10/22/85	248.8	241.1	248.6	248.7	253.4

Table B8

Ethylan Concentrations (ng/g Dry Weight)

in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	0.0
12/8/82	--	--	--	--	0.0
3/2/83	0.0	0.0	0.0	--	0.0
3/2/83	--	--	--	--	0.0
3/2/83	--	--	--	--	0.0
6/3/83	340.0	370.0	163.0	5.0	0.0
6/3/83	--	--	--	0.0	--
7/26/83	0.0	950.0	90.0	35.0	0.0
9/1/83	210.0	670.0	30.0	15.0	0.0
9/1/83	--	--	--	--	0.0
3/19/84	74.0	50.0	36.0	31.0	0.0
3/20/84	--	--	12.0	0.0	0.0
3/20/84	--	--	--	--	0.0
3/20/84	23.0	--	--	--	--
9/11/84	96.0	14.0	64.0	3.0	0.0
10/16/84	12.0	--	2.0	7.0	0.0
10/22/85	8.0	820.0	4.0	5.0	0.0

Table B9

PCB (A1254) Concentrations (ng/g Dry Weight)

in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
8/18/82	--	--	73	--	59
11/11/82	--	--	30	--	26
12/8/82	--	--	--	--	48
3/2/83	77	75	98	--	65
3/2/83	--	--	--	--	67
3/2/83	--	--	--	--	60
6/3/83	1,730	1,650	890	79	59
6/3/83	--	--	--	45	--
7/26/83	180	1,830	240	117	28
9/1/83	1,190	2,200	340	200	59
3/19/84	270	250	162	96	26
3/20/84	181	--	--	--	--
9/11/84	440	113	183	66	27
10/16/84	181	--	84	162	77
10/22/85	72	1,550	37	48	29

Table B10

Cadmium Concentrations (ng/g Dry Weight)

in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
3/4/83	0.36	0.34	1.06	0.29	0.24
3/4/83	0.39	0.35	0.44	0.21	0.22
3/4/83	0.35	0.49	0.32	0.25	0.22
6/3/83	17.00	13.90	7.30	0.74	0.22
6/3/83	12.40	14.70	4.20	0.58	0.21
6/3/83	13.00	12.90	3.70	0.64	0.19
7/26/83	5.40	11.70	1.14	0.64	0.22
9/1/83	4.10	9.80	0.84	0.68	0.18
9/1/83	21.00	8.70	3.60	0.76	--
12/9/83	8.80	8.70	3.30	1.02	--
3/19/84	2.10	1.11	0.85	1.08	0.20
3/19/84	--	0.87	--	--	--
3/19/84	--	0.23	--	--	--
6/12/84	3.10	4.80	0.37	0.39	--
9/11/84	3.70	0.73	0.97	0.30	0.20
12/20/84	9.30	2.50	0.32	0.72	--
10/22/85	0.45	8.30	0.29	0.32	0.16

Table B11

Chromium Concentrations (ng/g Dry Weight)

in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
3/4/83	56	39	59	59	48
3/4/83	53	57	43	58	52
3/4/83	45	56	56	60	54
6/3/83	870	680	340	69	49
6/3/83	780	740	191	72	48
6/3/83	800	600	155	74	48
7/26/83	120	519	69	66	44
9/1/83	310	600	106	79	56
9/1/83	680	380	160	79	--
12/9/83	520	660	117	126	--
3/19/84	100	52	54	86	47
3/19/84	--	140	--	--	--
3/19/84	--	40	--	--	--
6/12/84	138	210	41	52	--
9/11/84	153	41	128	55	44
12/20/84	550	175	47	88	--
10/22/85	54	430	57	59	40

Table B12

Copper Concentrations (ng/g Dry Weight)

in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
3/4/83	67	57	67	70	55
3/4/83	62	69	63	68	57
3/4/83	63	67	64	69	58
6/3/83	1,640	1,380	680	99	48
6/3/83	1,300	1,420	360	102	51
6/3/83	1,330	1,240	303	106	56
7/26/83	450	1,230	185	106	49
9/1/83	560	1,070	134	103	47
9/1/83	1,890	910	510	122	--
12/9/83	910	950	370	177	--
3/19/84	200	111	143	123	53
3/19/84	--	107	--	--	--
3/19/84	--	114	--	--	--
6/12/84	350	530	89	83	--
9/11/84	430	86	156	73	48
12/20/84	1,000	500	52	131	--
10/22/85	92	910	75	72	46

Table B13

Iron Concentrations (ng/g Dry Weight)

in Surficial Sediments

Date	Station				
	CNTR	200E	400E	1000E	REFS
3/4/83	21,000	17,100	22,000	23,000	19,700
3/4/83	20,000	22,000	18,900	23,000	21,000
3/4/83	18,400	21,000	21,000	23,000	22,000
6/3/83	17,100	19,200	23,000	21,000	21,000
6/3/83	19,300	19,000	22,000	21,000	19,000
6/3/83	17,900	18,700	23,000	22,000	21,000
7/26/83	15,200	16,700	21,000	16,800	21,000
9/1/83	15,100	19,300	21,000	18,400	19,700
9/1/83	26,000	15,100	--	16,400	--
12/9/83	16,500	21,000	19,600	17,500	--
3/19/84	5,800	17,300	20,000	18,700	21,000
3/19/84	--	16,600	--	--	--
3/19/84	--	15,600	--	--	--
6/12/84	6,500	17,100	19,800	15,600	--
9/11/84	12,600	17,400	18,400	18,200	21,000
12/20/84	18,100	17,300	17,400	18,000	--
10/22/85	9,900	17,200	18,100	18,900	17,000

END
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